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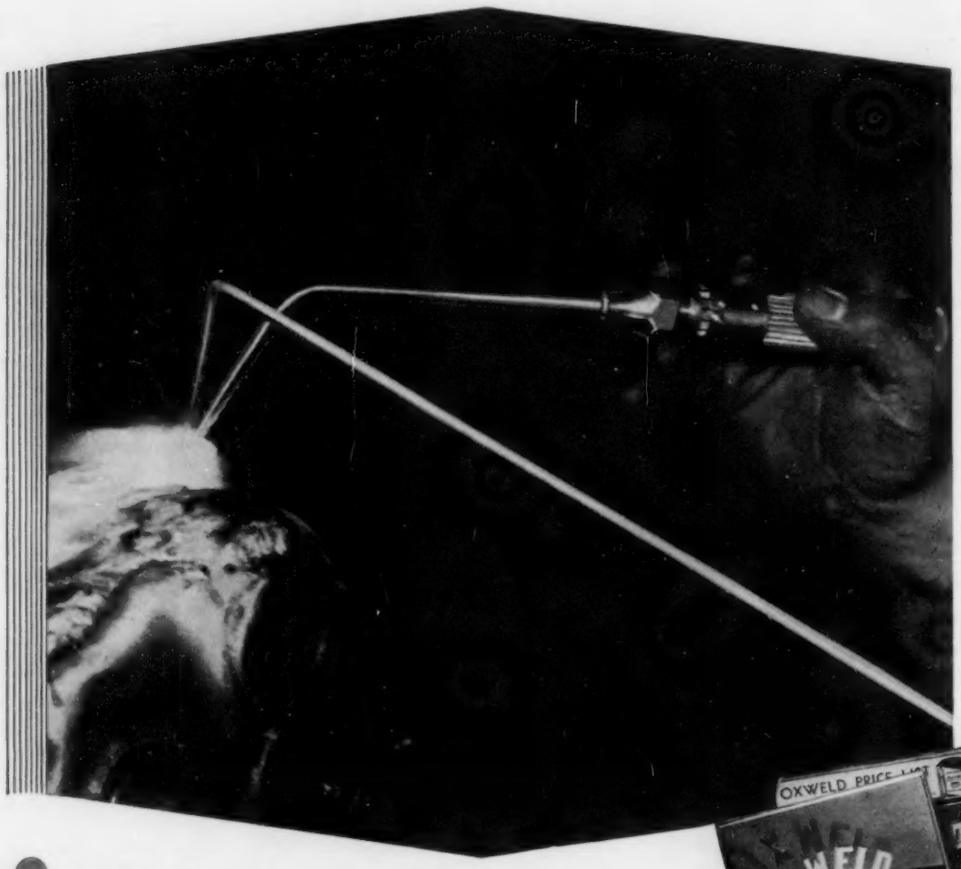

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THE
AMERICAN WELDING SOCIETY
JOURNAL

WM. SPRARAGEN, Editor | VOL. 14 | NO. 9

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The Development and Use of Low Alloy High Tensile Steels*

By A. E. GIBSON†

THE changing industrial and financial condition facing industry, as a result of the world-wide depression, is having a profound effect upon the development and design of mechanical and structural mechanisms. With the scarcity of orders and increased competition for such work as there is to be had, designers and fabricators of equipment have realized that lower first cost, lower operating cost and lower maintenance are of vital importance to the buyer. While most of us have realized for a long time that fabrication by welding permits, in many instances, advantages in these respects over the use of the older design of castings and riveting, too few realize the possibilities of a design which incorporates the new low alloy, high tensile and corrosion resistant steels obtainable from the leading steel companies.

Just as the automotive industry in America has shown

*Paper to be presented at Fall Meeting, AMERICAN WELDING SOCIETY, week of September 30, 1935, in Chicago.

† Vice-President, The Wellman Engineering Co.

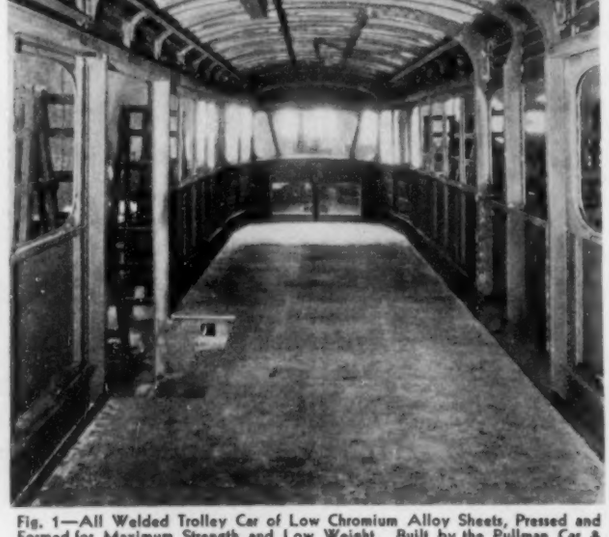


Fig. 1—All Welded Trolley Car of Low Chromium Alloy Sheets, Pressed and Formed for Maximum Strength and Low Weight. Built by the Pullman Car & Mfg. Co.

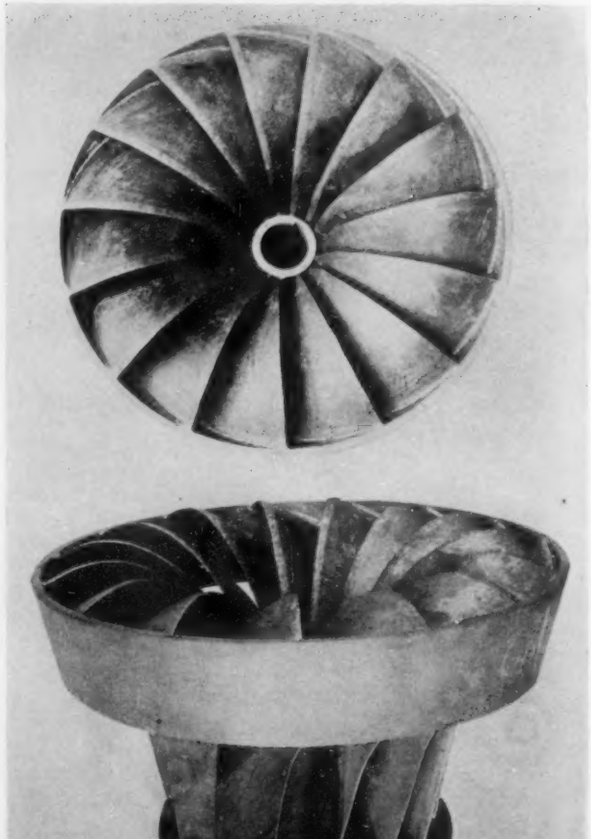


Fig. 2—Welded Steel Turbine Runners Fabricated by S. Morgan Smith Company, York, Pa., with Blades from Lukens Cromansil Steel Plates 1/2 In. in Thickness

those of us who are in other lines of manufacture, what production really is, so they have proved to us the value of alloy steels in the design of equipment of high physical value and low weight. This industry, above all others, has been alert, forward looking and progressive. They have given us the greatest dollar value ever known in America. It doesn't take much of a student to analyze this situation and realize that the developments were made for one reason only—sales. Some years ago we witnessed the situation in which the builder of what was for years the popular low-priced car sat idly by in the face of radical changes by competitors. The tremendous financial loss, running perhaps into a hundred million dol-

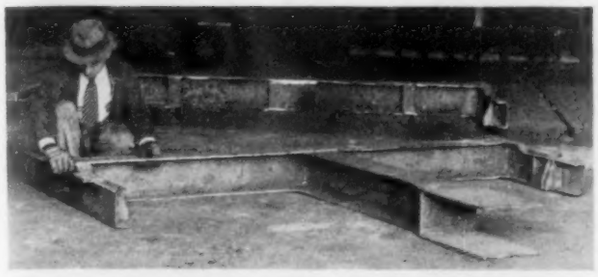


Fig. 3—Welded Steel Needle Beam Fabricated by Lukenweld, Inc., Entirely from Plates of Lukens Cromansil Steel (No Rolled Sections Employed) for Use on the Boston & Maine Railroad's "Flying Yankee" High Speed Stream-Lined Winton Diesel-Powered Train Built by the Edw. G. Budd Manufacturing Co. of Philadelphia

lars, the loss of sales, which in percentage has never been regained, should be an object lesson on trying to force upon the trade obsolete design in the face of modern and efficient competition.

We fabricators of moving mechanisms and material handling equipment are today in the same position as the automobile manufacturers of a few years past. Some of us are abreast of the times; some of us are dragging woefully behind. Let us see just what kinds of new steels are available. What are their physical properties; what can be accomplished with their use?

The steel industry in America, over a period of years, has spent and is continuing to spend, a vast amount of money and effort in developing steels of low alloy content having high physical values, many of them corrosive resistant and capable of being welded with the same technique, the same equipment and electrodes as used with low carbon steels. These investigations and experiments are numbered by the tens of thousands. The investigation of any analysis must be complete. In other words, reliance solely on tensile and bend tests is a dangerous procedure. An analysis may produce a steel, particularly under certain thermal treatments, with a very high yield and ultimate strength, with highly satisfactory bend and elongation but at the same time have an impact value decidedly unsatisfactory. Before any steel company can put one of these new materials on the market, before it dare stake its reputation on a new product, thousands of complete chemical, physical and metallographical tests must be made. This investigation is without end. What is new today is old tomorrow. Developments and improvements, new combinations of alloys are continually coming to the front, and without a doubt what we now consider to be the acme of perfection may be in a year or two a thing of the past.

These new steels are made of a large variety of alloys of varying quantity. Beyond stating that the most commonly used elements for increased strength are manganese, silicon, chromium, nickel, molybdenum and vanadium, no detailed discussion of the chemical properties will be gone into. This is a subject the discussion of which, even in a fragmentary way, would consume more time than is allotted to this address. To those unfamiliar with low alloy steels it will be of interest to know that the high physical values are obtained in most instances with relatively low carbon content. This condition is ideal for welding, as it eliminates, almost entirely, the objectionable air hardening experienced in welding steels of the higher carbon range.

There is one other element, not yet referred to, the use of which has a marked effect upon the physical values—copper. We are all familiar with the so-called copper-bearing steels which have been available for years and which are offered as corrosive resistant steels. There is no question that under certain conditions these steels, containing about 0.3% copper, are superior to ordinary low carbon steels in resisting corrosion. It is only of recent date that the steel industry has come to know the value of copper, in larger proportions than formerly used, in increasing the physical values. This is especially outstanding regarding the ratio of yield point to ultimate strength, particularly under certain thermal treatments. Even in the as-rolled condition, a 2% nickel steel with 1% copper will have a yield point 50% higher than that of same analysis without copper. Giving this same steel, with the copper, a thermal treatment of 950° F. and air cooling will increase the ultimate strength about 20% and will increase the yield point nearly 40%. This increase of yield and ultimate strength of copper steels, subjected to low thermal treatment, is known as precipitation hardening. The limit of solubility of copper in solid iron is about 0.35%. Excess of copper over this amount precipitates out into the crystallographic planes, and when the steel is heated from 900 to 950° F. and fairly rapidly cooled, effects what is known as precipitation hardness in the metal. The striking physical properties of high copper content steel combined with such alloys as nickel and molybdenum are shown in Tables 1 and 2. It will be of interest to know that yield points in butt welds on $^{3}/_{8}$-in. and $^{1}/_{2}$-in. plate are above 80,000 lb. per sq. in., and ultimate strengths above 90,000 lb. in the as-welded condition. Under certain thermal treatments the yield and ultimate strength are as high as 93,000 lb. and 104,000 lb. per sq. in., all with fine qualities of bending and low Brinell hardness.

The steels generally accepted and widely used in the low alloy range, in the as-rolled condition, have yield points from 50,000 lb. to above 70,000 lb. per sq. in., ultimate strength from 70,000 lb. to 100,000 lb. per sq in., elongation in 2 in. from 20% up, free bend tests of 180° and high values of fatigue and impact. Naturally, in welded structures, one must consider the strength of the welded joint, but rarely is it impossible to obtain welded joint strengths greater than that of the parent metal. This is true because in most instances increased sections can be obtained by the use of reinforcements or fillets in addition to complete penetration of the metal. Therefore, as a general rule, it is possible to use the yield point of the rolled metal as a basis for figuring. Yields of 50,000 to 70,000 lb. per sq. in., in comparison with an average of 32,000 lb. per sq. in. for low carbon steel, is an increase of 56 to 118%. While it is recognized that reductions in weight cannot be obtained to this extent, it has been proved possible to effect savings in weight from 30 to 50% in the use of low alloy welded structures over previ-

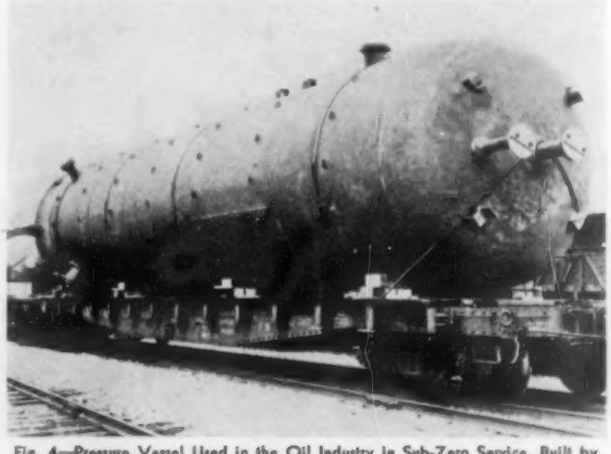


Fig. 4—Pressure Vessel Used in the Oil Industry in Sub-Zero Service, Built by A. O. Smith Corp., Milwaukee, Wis., from Plates and Flanged Heads of Lukens Nickel Alloy Steel

Table 1

Copper-Nickel Steel

C	Ni	Copper
0.08	1.99	1.02

Tests by Steel Mill and Wellman Engineering Company

	Y. Weld	Y. Parent	Ult.	% El. 2 In.	% Red.	Break
As-Welded Mill	57,000		63,000	29	70	Parent Metal
As-Welded Mill	65,000		69,000	26	66	Parent Metal
As-Welded W. E. Co.		55,800	65,300	33	54	Parent Metal
As-Welded W. E. Co.		55,800	65,900	34	56	Parent Metal
950° F. 1 Hr. Mill	80,000		83,000	24	57	Parent Metal
950° F. 1 Hr. Mill	72,000		84,000	20	37	Weld Metal
950° F. 1 Hr. W. E. Co.		63,500	80,000	31.5	51	Parent Metal
950° F. 1 Hr. W. E. Co.		63,400	80,400	31	52	Parent Metal
1200° F. 1 Hr. Mill	57,000		71,000	29	64	Parent Metal
1200° F. 1 Hr. Mill	70,000		73,000	29	64	Parent Metal
1200° F. 1 Hr. W. E. Co.		68,100	71,500	31	51	Parent Metal
1200° F. 1 Hr. W. E. Co.		63,000	70,900	25.5	54.5	Parent Metal
1650° F. 1. Hr. Mill.	55,000		68,000	35	62	Parent Metal
1650° F. 1 Hr. Mill	53,000		68,000	33	60	Parent Metal
1650° F. 1 Hr. W. E. Co.		51,400	65,600	42.5	59.5	Parent Metal
1650° F. 1 Hr. W. E. Co.		50,600	65,600	40	63	Parent Metal

C	Ni	Copper
0.22	1.98	0.92

	Y. Weld	Y. Parent	Ult.	% El. 2 In.	% Red.	Break
As Welded	85,600	72,000	95,400	27	42	Parent Metal
As Welded	85,200	66,300	91,800	27	44	Parent Metal
950° F. 1 Hr.	82,600	85,000	90,300	9	16.6	Weld, Slag Inclusion
950° F. 1 Hr.	78,500	94,000	100,800	18.5	32.6	Weld
1200° F. 1 Hr	69,300	78,800	88,300	16.5	24	Weld
1650° F. 1 Hr.	64,400	69,000	81,300	17.5	38	Weld
1650° F. 1 Hr.	65,300	70,300	79,750	14	14.5	Weld, Slag Inclusion

2% Nickel Steel

C	Nickel	Y	Ult.	% El. 8 In.	Red.
0.10	2.00	35,000	50,000	28	60

Tests of nickel-copper steel with low and medium carbon. Two distinct yield points are obtained in the physical tests, one of the parent metal and one of the weld. In the low carbon copper-nickel steel the yield of the weld is higher than that in the parent metal. Note the high strength of copper-nickel steel in comparison with the 2% nickel steel shown in the bottom line of the table.

ous designs of low carbon steel. The saving in weight in such equipment as diesel engines, where welded low alloy steel is substituted for cast iron, is even more marked. The Winton Engine Company of Cleveland have made remarkable improvements in redesigning their welded construction, thus obtaining 500 hp., while the older cast-iron design of the same weight produced but 300 hp. This development has become standard for submarine service where every pound of weight saved is of vital importance. We have recently received Navy specifications on other equipment, which state that weight increase or decrease will be credited or penalized at the rate of fifty cents per pound—an indication of the importance of light weight.

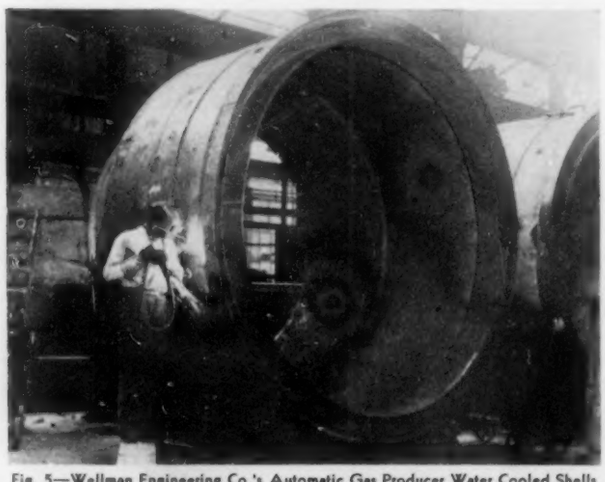


Fig. 5—Wellman Engineering Co.'s Automatic Gas Producer Water Cooled Shells Completely Welded of Corten Steel. Ten-Foot Inside Diameter, 5/16-in. and 3/8-in. Plate

In redesigning our drag line buckets, using high tensile chromium, manganese, silicon welded steel, which we buy on a specification of maximum 0.20% carbon and minimum 60,000 lb. yield, we have obtained weight reductions of over 30%. When it is realized that with a crane of fixed capacity one can obtain for instance with a two cubic yard bucket, an additional pay load of over 1000 lb., and that the cycle of operation is less than one minute, the use of light weight equipment is decidedly a paying proposition. Another of the advantages from the use of welded low alloy steel is that we are able to make guarantees undreamed of with the older cast design.

We build heavy duty dredging clam shell buckets. Until recently these have been a combination of steel castings and low carbon rolled plate. The service is severe and although we have used alloy steel castings in the past, there has always been considerable breakage. In an effort to overcome this, we have redesigned these buckets, eliminating the castings in those parts highly stressed, and have substituted welded construction of low alloy steels normalized for strain relief and grain structure. As a result we are now offering this equipment with a full guarantee against breakage. The question of why we can guarantee alloy steel in welding while it is not satisfactory in castings is a pertinent one. It is possible to obtain the same yield, tensile and bend properties in a casting as in rolled plate, but there are certain inherent complications in the making of castings, par-

ticularly those having sudden and pronounced changes of section, which are most difficult to overcome. I think I can present this difficulty to you very clearly by calling to your attention the experiments which all of you have no doubt seen with polarized light stress distributions in a model representing two pieces of steel forming a "T" and joined with two fillet welds, leaving an unjoined contact between the welds. You know of the high stress concentrations in the welds as a result of the opening between the parts. This is one of the conditions met

Table 2

Cromansil Steel

Mill Report

C	Cr	Man.	Sil.	Y	Ult.	% El
0.14	0.47	1.24	0.76	61,700	90,900	25
0.21	0.55	1.29	0.75	70,100	99,800	23

Manten Steel

C	Man.	Sil.
0.27	1.54	20.4

	Y	Ult.	% El.	Red.	Failure
As Rolled	58,340	94,000	8 In.—22	57.9	
As Rolled	54,420	90,660	8 In.—18.7	37.5	
As Welded	54,100	88,630	2 In.—14		Weld
As Welded	53,880	89,640	8 In.—19.5	58.8	Parent
As Welded	55,600	88,900	2 In.—15		Weld

Corten Steel

C	Man.	Sil.	Cr	Cu
0.09	0.22	0.508	0.97	0.38

	Y	Ult.	% El.	Red.	Failure
As Rolled	50,780	74,800	8 In.—23 2 In.—40	58	
As Rolled	50,790	73,310	8 In.—23 2 In.—42	52.7	
As Welded	50,890	75,340	8 In.—24	57.8	Parent
As Welded	50,060	74,510	8 In.—22	61.6	Parent
As Welded	50,100	73,120	8 In.—22.5	63.5	Parent

Copper-Molybdenum Steel

C	Molyb.	Copper
0.25	0.25	1.40

	Y Weld	Y. Parent	Ult. Weld	% Red.	% Bend	Failure
As Welded	79,870	90,760	93,740	28	180	Weld
950° F.—1 Hr.	88,390	95,270	98,740	31	141	Weld

Copper-Nickel-Molybdenum Steel

C	Ni	Copper	Molyb.
0.23	0.75	1.30	0.16

	Y. Weld	Y. Parent	Ult. Weld	% Red.	% Bend	Failure
As Welded	80,590	90,880	96,460	29	149	Weld
950° F.—1 Hr.	93,870	102,920	104,620	28.8	127	Weld

Rolled plate and weld values o some of the popular low alloy high tensile steels, indicating the high value of yield to ultimate strength with exceptional ductility.

Table 3

Chemical Analysis

C	Mn	S	P	Si	Ni	Cu
0.24	0.67	0.020	0.048	0.26	1.97	0.92

Physical Properties

Treatment	Yield Point	Ult. Str. Lb./Sq. In.	El. % in 2 In.	Reduction in Area	Charpy Impact	"B" Scale Rockwell Hardness	Brinell Hardness
Hot Rolled	61,000	88,000	27	57	25	89	162
Norm. at 1450° F.	68,000	92,000	28	58	32	89	159
Norm. at 1650° F.	71,000	92,000	28	58	33	89	160
Norm. 1650—Renorm. 1450°	72,000	93,000	28	58	34	87	160
Norm. 1650—Renorm. 1375°	66,000	89,000	28	58	35	89	162
Norm. 1800—Renorm. 1450°	61,000	87,000	28	58	29	88	166
H. R. and Heated 900° F.—4½ Hr.	82,000	107,000	25	54	16	95	196
Norm. at 1450°—Heated 900° F. 4½ Hr.	82,000	105,000	25	54	23	93	202

The best Charpy impact accompanied by good tensile and ductility is obtained by normalizing from 1450° F. to 1600° F., there being very little difference between these two normalizing temperatures.

The above table of physical properties indicates the value of thermal treatment of low alloy high tensile steel. The maximum yield and tensile values of high copper-nickel steel result from precipitation hardening at 900° F. but with an alarming drop in impact value.

with in castings having unequal metal in adjoining sections, resulting in shrinks and is the cause of most of the failures encountered in heavy duty buckets. We have overcome this in welded low alloy steel construction by complete penetration of the welds and in normalizing the completely welded detail, we obtain not only elimination of rolling and welding strains but obtain grain structures giving high physical properties of tension, bending, fatigue and impact. Naturally, with sufficient stress, it is possible to break any structure, but we are confident of our welded joints, knowing that they are stronger than the plate used and if a failure occurs it will not be in the weld. We have been surprised by the accord with which this new design has been received. We have been equally surprised by the knowledge of welding displayed by the users of this type of equipment and their confidence in welding in general and in high tensile *normalized* welded equipment in particular; this in the face of a price in-

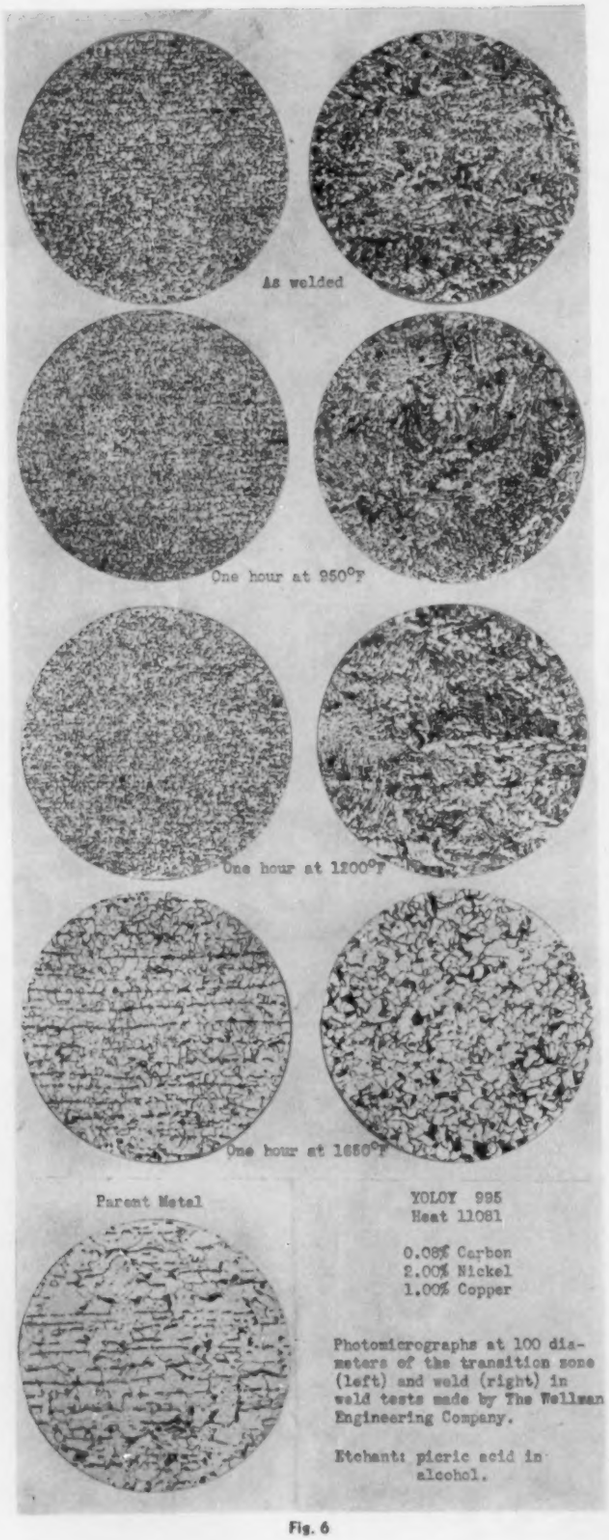

As welded
One hour at 950°F
One hour at 1200°F
One hour at 1650°F
Parent Metal
YOLOY 995
Heat 11081
0.08% Carbon
2.00% Nickel
1.00% Copper
Photomicrographs at 100 diameters of the transition zone (left) and weld (right) in weld tests made by The Wellman Engineering Company.
Etchant: picric acid in alcohol.

Fig. 6

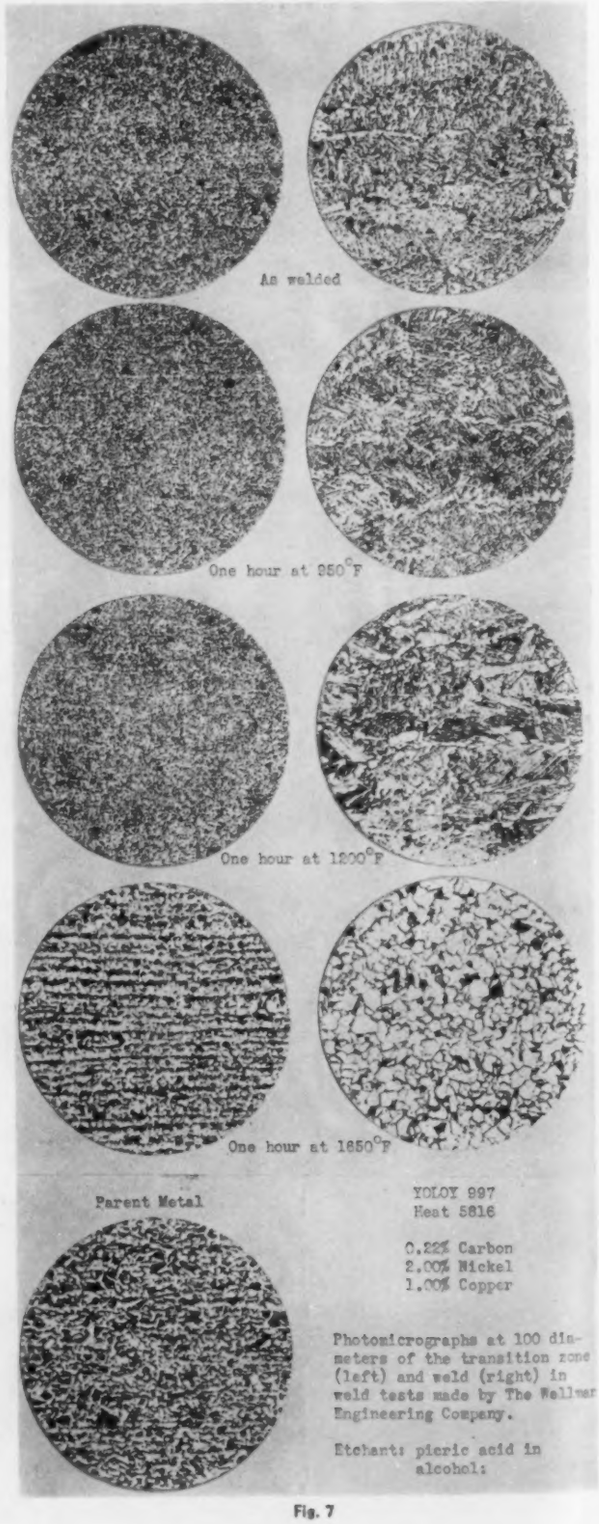
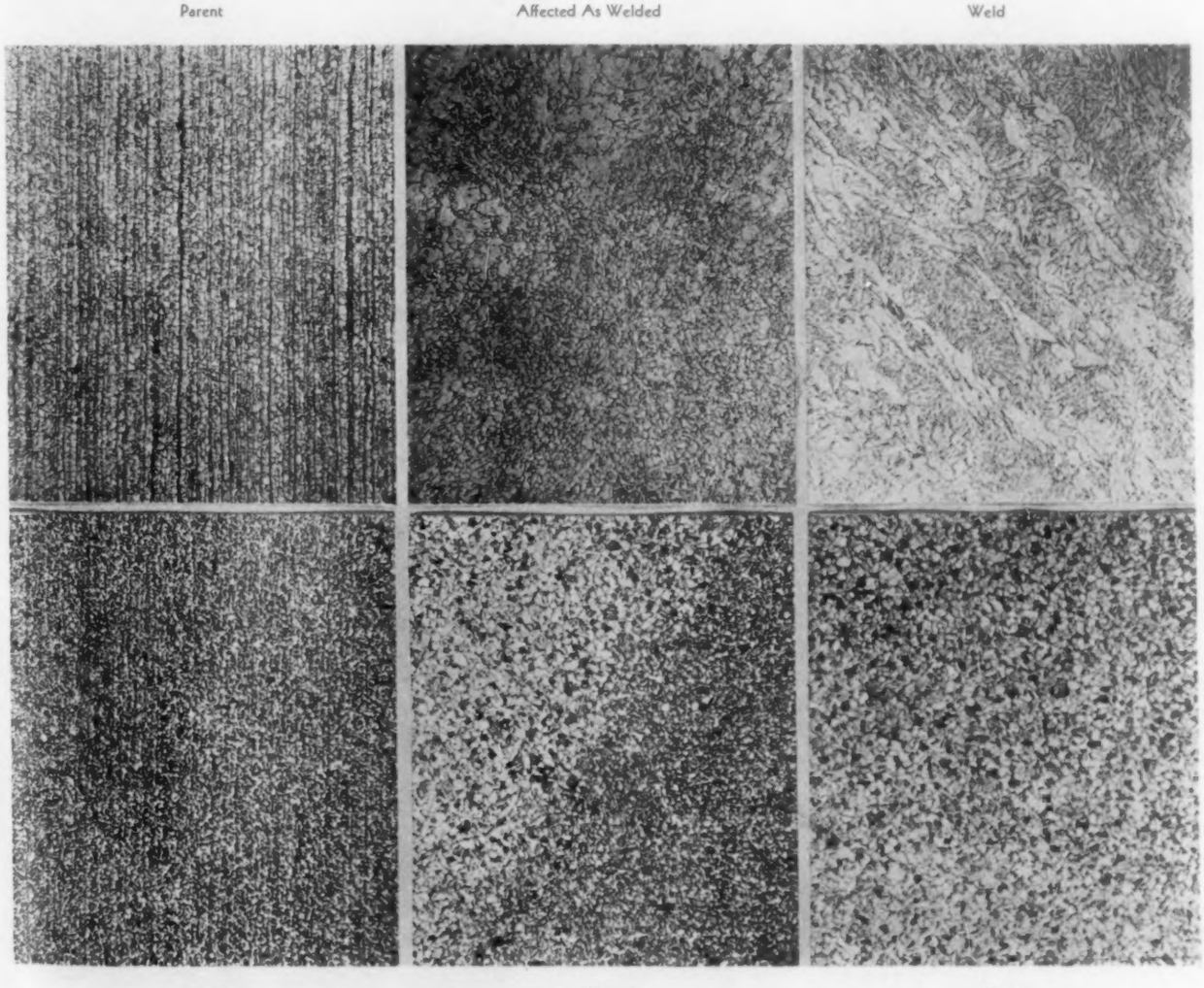

As welded
One hour at 950°F
One hour at 1200°F
One hour at 1650°F
Parent Metal
YOLOY 997
Heat 5816
0.22% Carbon
2.00% Nickel
1.00% Copper
Photomicrographs at 100 diameters of the transition zone (left) and weld (right) in weld tests made by The Wellman Engineering Company.
Etchant: picric acid in alcohol.

Fig. 7

crease of 25% over the older design. American industry is learning that low first cost does not necessarily mean low ultimate cost, and that service free from breakdowns and constant repairs is a type of insurance warranting an initially higher first cost.

We referred to the property of corrosion resistance in many of the low alloy steels. While no exact figures on corrosion loss are to be had, the statement frequently made during the height of the depression that the rate of corrosion was greater than the rate of ingot production was not just a figure of speech. In spite of the expenditure of hundreds of millions of dollars for protection against corrosion the battle can never be won, it can only be prolonged. From the best information at hand we believe that the life of corrosive resistant steels of copper or phosphorus content is from three to six times as long as ordinary steels. On that basis it would appear that the extra cost would be in a large measure justifiable. We have been corrosion conscious for so short a time that definite data on these steels have not been established. Accelerated corrosion tests are at best but approximations and too much reliance should not be placed upon them. Under such adverse conditions as sulphur water encountered in mines, in the transportation of coal, and in many industrial plants, where acid fumes are liberated, the rate of corrosion is a vexing and costly problem. Many of our railroads are carrying on extensive investigations in freight cars, where light weight and corrosion resistance properties of low alloy steels offer much promise.

In welded construction, the inherent value of heavily coated metal electrode welds, in regard to corrosion, is well known. It is the writer's belief that at least with reinforced welds, the life of the weld will be as great as the parent low alloy metal. However, there is no reason why we cannot produce welds with approximately the same analysis as the parent metal. Some of our leading electrode manufacturers have had a variety of low alloy rods on the market for some time, and these alloy rods make possible much higher strength welds. In the building of welded structures incorporating high tensile low alloy steels, only partially do we obtain the maximum potential values if the welding is not followed by suitable thermal treatment. So far as stress relief is concerned, there have been two schools of thought, one advocating thermal treatment and the other peening. Those of us giving serious consideration to the fundamentals of the problems to be faced in successful welding, realize the unfavorable grain structure resulting from welding heat reactions. The only way to correct this condition is to subject the welded piece to the proper thermal treatment. If it is desired to obtain as uniform



1650° F. Normalization, 100×

Fig. 8—Copper-Nickel-Molybdenum Steel

Fig. 9—Wellman Engineering Co. Welded Heavy Duty Dredging Bucket, Weight over 20,000 Pounds, of Cromansil Steel Normalized. A Design Permitting Guarantees against Breakage Impossible with a Cast Construction

as possible a grain structure in the parent metal, the affected zone and the weld, it is necessary to go to rather high temperatures, preferably above the critical point of the particular steel, and then to lower the temperature through the critical range rapidly. While all high tensile low alloy steels result in highly satisfactory grain structure and physical properties under this treatment, they do not produce the maximum of physical results in all respects. It would be dangerous to set any definite procedure covering all steels, because they do not all react alike. Reference to this was made in the early part of this article in connection with copper bearing steels. The statement was made that high copper steel has the property of precipitation hardening under certian heat reactions. It is an interesting phenomenon that the results, so far as impact values are concerned, vary widely with 1% or more copper in steels containing medium carbon. Charpy impact values will drop as much as 50% under precipitation hardening, and this is a matter deserving serious consideration, particularly in equipment subjected to shock. However, there is no excuse for any-one blindly blundering into difficulties, as every manufacturer of low alloy steels can give you full chemical, physical, and if you are interested, metallographical and heat treatment information on the particular steel in question. Unfortunately, they are not in the position to furnish as complete data on the value of welds, but they are learning fast and they have an intriguing way of getting some of us fabricators to work out the welding data for them. However, there is a community interest between the steel makers and the welding steel fabricators, and, I am glad to say, a willingness to work together for the common good which is accomplishing much.

The writer realizes that with the possible exception of the pressure vessel field, it is difficult for a manufacturer to "sell" a customer on such refinements as low alloy high tensile steels correctly thermally treated, but I can assure you from our own experience tabulated results, showing heretofore undreamed of physical values and weight reduction, and photomicrographs of grain structures, which even though they may be as "clear as mud" to the purchaser, at least leave him with the impression that here is a manufacturer who must know what he is doing. It has sold more welding at decent prices than anything else we have tried.

The Welding of Low Alloy Steels*

By J. C. HOLMBERG†

RECENT years have seen a marked advent of alloying elements for steel in plate form. Ten or fifteen years ago one would have been ridiculed had he mentioned or even thought of using the so-called boiler plates with tensile strengths higher than the generally accepted 55,000 pound per square inch materials then available. Popular opinion decreed that materials having greater strengths must of necessity be hard, and by the same token, brittle.

The forging and the automotive industries have thoroughly discredited this theory. The use of alloys to increase the strength of forgings and automobile parts was taken advantage of many years ago. Undeniably, one of the reasons for this was that the motor car people were engaged in a newly developing industry unhampered by precedents long established; therefore could take full advantage of new ideas fostered by the metallurgists of the steel industry.

The oil industry in recent years has inaugurated new processes with the result that pressures and temperatures unheard of, even as late as during the war, have become common in this field. To withstand these pressures it was obviously necessary to increase the wall thicknesses of the vessels.

In riveted construction a point is soon attained where riveting becomes impracticable as a means of joining structural elements. Welding, as we all know, was the natural recourse.

* Paper to be presented at Fall Meeting, AMERICAN WELDING SOCIETY, week of September 30, 1935, in Chicago.

† Chief Metallurgist, Struthers Wells-Titusville Corporation.

Through welding a considerable weight saving was effected and joint efficiencies increased. Further increases in pressures, more drastic service conditions, such as high and low operating temperatures, finally paved the way for the introduction of alloy elements into boiler plate. To me, as a metallurgist, it appears that these alloys were introduced tardily and that the benefits to be derived were not quickly utilized.

The welding industry discovered some time ago that plates of certain heats had better welding characteristics than others; also particular spots in some plates did not exhibit the desired welding characteristics anticipated. Investigation soon disclosed that the plate material was not as homogeneous as reasonably expected. We all know the bulk of ordinary plate is popularly termed rimming steel and, from the steel maker's standpoint, this is the desired product as it produces less discard and better surfaces. It also creates a non-uniform product, so that it was not long before important buyers of welded pressure vessels commenced specifying silicon killed steel. This increased the silicon content considerably, made a much more uniform and weldable plate both as to composition and working qualities. I believe this might really be termed the first of the higher strength steels. It did not achieve higher strength so much from the small addition of silicon as by greater cleanliness and uniformity.

During the past few years all the important plate manufacturers have started producing low alloy plate material and their position in doing so has been difficult. Regulatory bodies have long decreed certain formulas for the computing of strengths and for many years, irrespective of the physical properties of the material, full advantage of these could not be taken when the vessel was going to be under the structural supervision of the aforementioned bodies; recent changes have been made in the code regulations which permit fabricators to take advantage of the higher strengths of the new material.

It is hard to so control and regulate the alloy content that the resulting steel will be suitable for welding purposes without introducing hazards and mechanical difficulties for the builder. The steel must be limited as to its air hardening characteristics. Hardness in the fusion zone or material adjacent to the weld must not be excessive, or the differential between this area and the balance of the plate might tend toward cracking. The material should be of such a composition as to be readily cut by means of the oxyacetylene flame and must lend itself to forming and spinning, and the indicated heat treatment must be simple. Obviously it is impossible to heat treat a welded vessel in the same manner as a large forging. The vessel cannot be quenched in water, nor can it be annealed at high temperatures, as any deformation would be disastrous. Thus the heat treatment automatically limits itself to narrow limitations of that decreed by the Code Authorities; which is to stress relieve, as the rules of the Code Authorities are strict.

Probably the best known of the new higher strength steels is that produced by the Lukens Steel Company and called "Cromansil." This alloy, as its name indicates, contains roughly about half of one per cent chromium, 1.25 per cent manganese and around 0.90 per cent silicon.

United States Steel Corporation have introduced three (3) new plate materials, namely: Cor-ten, Man-ten and Sil-ten. Typical alloy additions for these are:

Cor-ten has chromium, copper, silicon and phosphorus. These alloys result in an increased strength and corrosion resistance.

Man-ten, as its name indicates, is a higher manganese steel with a tensile strength fifty per cent greater than ordinary flange steel.

Sil-ten is one of the higher silicon steels of high tensile strength.

The Republic Steel Corporation has developed and are marketing a Republic double strength steel—a nickel-molybdenum steel which shows excellent physical properties; and the Youngstown Sheet & Tube Company are producing Yoloy which is a nickel-copper steel of greatly improved strength and corrosion resistance.

Strangely enough the advent of these new alloys in the fabrication industry has not been attended by the furore usually associated with the introduction of new and unique materials. Possibly the reason for this is that except for stiffness its forming qualities are similar to those of carbon steel. Too, the welding of this material has not been as difficult as is often anticipated.

The duplication of the analysis of plate material in a weld, is, in these alloys, much more difficult than in the welding of carbon steel. While many of the elements can be transferred from the electrode to the deposited weld metal during the act of welding, some will suffer considerable losses, and unless great care is exercised the deposited weld metal will be appreciably lower in alloy content than the plate.

For example, vanadium. We are all familiar with the fact that vanadium oxidizes readily and in the superheated atmosphere of the arc practically all of it is lost and thus very little, if any, remains in the weld. Titanium is another alloying element that at the present time I do not believe can be successfully introduced into the weld metal. This is particularly unfortunate because perhaps no two alloys have greater scavenging qualities and their introduction would be of considerable value.

For strength, impact and corrosion resistance the alloy most commonly used to increase the physical properties of the deposited metal is molybdenum. This alloy is one of the most potent we have in the steel industry. Comparatively small amounts have a decided effect upon the physical properties. It is soluble in both gamma and alpha iron and also forms complex carbides; enabling the materials to retain these carbides in solid solution upon cooling from temperatures above the critical range and this explains the increased strength of the molybdenum alloys. Molybdenum tends to inhibit grain growth and increase the strength of the steel at elevated temperatures and their resistance to creep. In our own experimental work we have been able to introduce as high as 1% molybdenum into the deposited weld metal through the addition of this alloy to the coating of the electrode; and I believe that most of the higher strength electrodes being marketed by suppliers depend largely upon the addition of molybdenum to give them physical properties comparable to those of the new plate material.

Nickel is often used. This is another element that can be readily transferred from electrode to deposited metal without suffering a loss. It will also unquestionably be used still more extensively with the increased popularity of the new steels which have a nickel content; also the $3\frac{1}{2}\%$ nickel steel which is coming into popular usage for vessels intended for extremely low temperature service. The effect of nickel is to increase the strength, yield point and hardness with less loss in ductility than is usually suffered through the increase of these values, where they are obtained by additional carbon content. These characteristics are very valuable in welded structures where it is impossible to use

heat treatment indicated by the chemistry of the material. A standard formula with reference to nickel has been that 1% of nickel would increase the elastic limit and tensile strength approximately 4000 pounds per square inch and would decrease elongation about 1%. This decrease in elongation is the result of the necking characteristic of nickel steels when tested in a standard tensile machine.

Perhaps nickel's one pronounced drawback is that under certain conditions nickel steel will "flake" or thermal check. These fine cracks, microscopic in size, are caused by too rapid rate of heating and cooling through critical temperatures. At this particular temperature the material is exceedingly fragile and the expansion of one portion or contraction of another will cause a severance or cleavage. This is mentioned at this time merely as a point of interest and not to cause undue alarm, as I do not believe this condition will exist in plate materials or welds of thicknesses encountered in fabrication today. I do believe that in plate thicknesses exceeding 6 in. precautions will have to be taken to eliminate this hazard and if that time arrives we will probably find the same microscopic crack in other materials as well. In the forging industry we have found that no steel is exempt from this fault even though the nickel steels are the most susceptible.

Practically all of the alloy plate producers are able to supply electrodes of suitable composition for the welding of their products. Many of these are so balanced that the analysis of the deposited metal will be very similar to that of the plate. Others previously mentioned depend on a molybdenum content to supply the weld with the desired strength.

In Warren our practices for the welding of these steels are the same as that used for the plain carbon steel, although slight modifications are naturally indicated. The material has a higher elastic limit and it follows that rigidity is greater so that extreme care must be taken in assembling component parts. If possible, straightening or reforming should be prevented as areas adjacent to the weld prior to final heat treatment are often appreciably harder and do not lend themselves to plastic deformation in the same way as mild carbon steel. Through the use of carefully selected electrodes we are daily duplicating the physical properties of the plate material. I have in mind a weldment just completed, made of one of the new molybdenum plate materials; we introduced approximately 0.90% molybdenum into the weld. The physical properties secured on this from a standard 0.505-in. all weld metal tensile test were:

Tensile strength	82,000 lb.
Elastic limit	55,000 lb.
Yield point	60,000 lb.
Elongation	28%
Red. of area	55%
Brinnell on this piece	179

The elastic limit on this test was secured with an extensometer, in accordance with the U. S. Navy practice.

The welding technique employed was practically the same as what we customarily employ for carbon steel. The weld groove details were the same and preheating employed only to remove any chill in the material. As is our standard practice we preheated this structure as we have found this process to be a preventative of distortion.

Welding was performed with $^1/_4$-in. electrodes using carefully regulated current to prevent overheating of the material.

After welding had begun there was no letup as we have found starting and stopping is a destructive practice and does not insure superior micro-structure.

This weldment was subsequently heated slowly to a temperature of 1250° F., maintained ninety minutes for each inch of cross section at this exact temperature and then permitted to grow cold in the annealing furnace.

Thus you will see the addition of alloying elements has, in most instances, resulted in a bilateral benefit; strength of material at elevated temperatures has been increased and, conversely, the transformation points lowered. We are able through these two results to secure a much more adequate heat treatment. This higher temperature enables us to better equalize the differences between the deposited weld metal and the adjacent plate material, making for a much better job through a greatly increased uniformity of the structure.

The addition of the new alloy plates to welding materials has practically completed the list of materials from which the buyer of weldments, whether vessel or fixture, has to choose.

We who have been in close contact with the art have seen it grow from the bare wire repair welding to its present universal use for construction and maintenance.

We have seen the stainless alloys introduced and become common and many of the non-ferrous alloys have played an important part in the development of the welding art, and now through the history of alloy usage in the forging industry I do not hesitate to say that the day will soon come when ordinary mild flange steel will be largely displaced in the welding industry by the lower alloy steels, giving us structures that are lighter in weight, more resistant to corrosion and greater in strength.

Fall Meeting

All members of the Society are urged to attend the Fall Meeting to be held in Chicago, September 30th to October 4th, and to bring their friends. As indicated in the program published elsewhere in this JOURNAL, an unusual number of very good papers covering many phases of welding will be presented.

Outstanding other events are the Exposition, Milwaukee Night Wednesday evening, the Annual Banquet Thursday evening and the inspection trip Friday, October 4th.

Handling Distortion in Maintenance Welding Problems

By GEORGE W. HETTRICK†

WHERE welding is employed in plant maintenance, its application is largely that of repair. It may be a fractured casting, a broken punch press frame, a worn shaft or a discarded part, which has been reclaimed from the scrap pile and repaired by welding, to form an essential part of some machine or piece of equipment in the plant. The welded part must, of course, be in perfect alignment and free from strains and stresses to be of any use to the owner.

Not only is repair welding a money-saver to many industrial plants, but often it is the only way in which equipment can be replaced within a short time.

† President, Anchor Welding Service, Inc., Chicago, Illinois.

The individual applications of the welding processes, whether they be gas, arc or thermit are without number. The economic and practical use of these processes requires a knowledge of: first, correct technique; second, physical properties of various metals and their action under the welding flame; third, economies and practicability of the various processes; fourth, equipment required; fifth, ability of the plant's welding department or of the welding contractor to properly prepare casting for welding.

Too much emphasis cannot be laid on the need of an understanding of fundamentals in the repairing of equipment by welding. An improper application of welding may result in the failure, which is apt to make the management skeptical of welding in general, and to

Fig. 1—Broken Vertical Milling Machine

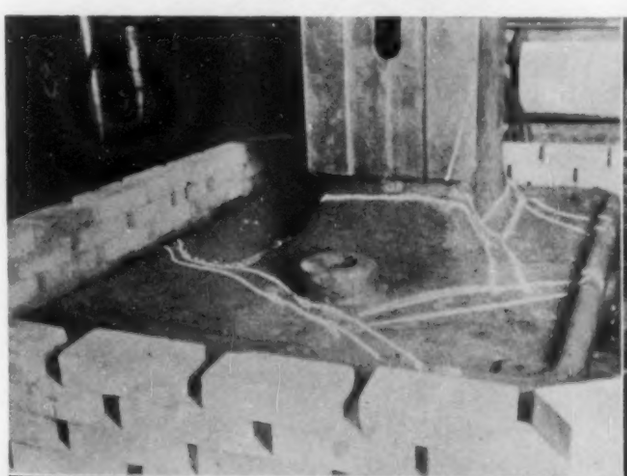


Fig. 2—Work Setup Preparatory to Firing

Fig. 3—After Firing Welding Started

Fig. 4—Completed Job

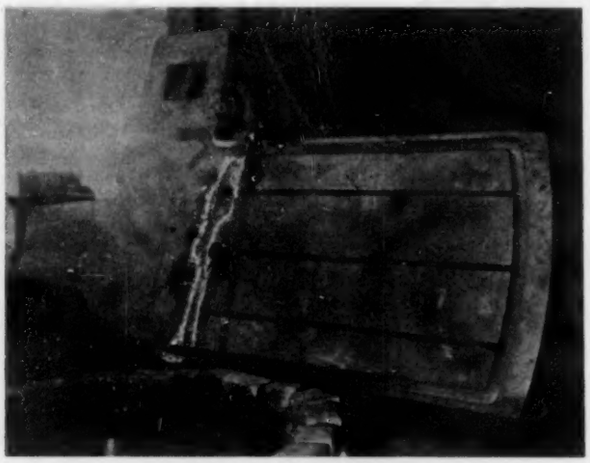


Fig. 5—Broken Radial Drill Press

create a situation which shuts the door to the use of the welding processes, thus preventing the economies which such processes effect in time and labor.

The job welding shop was the pioneer of the welding industry, but today is considered only a small portion of the industry, due principally to the fact that every shop that has a welding outfit is considered capable of handling all classes of welding. The average layman not familiar with the art of welding loses respect for the process simply because an inexperienced man has made a failure of his particular job, when in reality the welder should be held responsible and not the process.

There are also plant managers who have purchased welding equipment that really believe that any ordinary man with the average intelligence can learn to handle his welding repairs in a few weeks, or months. This, of course, is not true.

The welding of broken machinery parts requires a great deal of experience. The average welder has been trained to certain work, it may be the welding of defective foundry castings or the welding of spouts on coffee pots. In either case this man is of practically no use to a job shop contractor. A man to be successful in repairs of machinery must have experience in this particular field. He must understand expansion and contraction to enable him to properly pre-heat a casting and he should have a general knowledge of machinery and its operations.

One of the faults the average welder has is that he is unable to secure a sound weld at the bottom of the fracture of a heavy section, which is very essential to good welding. In a good many cases the writer has come across welds with 3 in. penetration when the section itself was 6 in. in thickness. This class of work can result in nothing but failure.

The plant welding department or job shop must have proper facilities for handling this class of work. There should be a space set aside with a brick floor, a high ceiling and plenty of ventilation, also overhead crane facilities to enable proper handling of any heavy sections.

Practically all heavy cast-iron machinery parts should be pre-heated before welding. The principle reasons for this are: to take care of expansion and contraction, eliminate distortion and secure a sound machinable weld. Also preheating of cast iron is a great saver of oxygen and acetylene. The most successful fuel for pre-heating is charcoal, due to its slow starting and uniform heat. However, in some cases of small sections city gas and compressed air, or kerosene blowtorches are used with good success.

For a good many years our company has been using a method of tack welding heavy sections in place before pre-heating. Illustrations accompanying this paper will show this method clearly. It consists of lining up casting to be welded and after both halves have been properly shimmed and casting having been checked for alignment, the electric arc is then used, with tacks placed at four or five inch centers. Should the break fail to close up tight before tacking, as frequently caused by small loose particles of metal in the fracture, it will be found that as the arc weld cools it draws these two sec-

Fig. 6—Broken Metal Brake Press Head

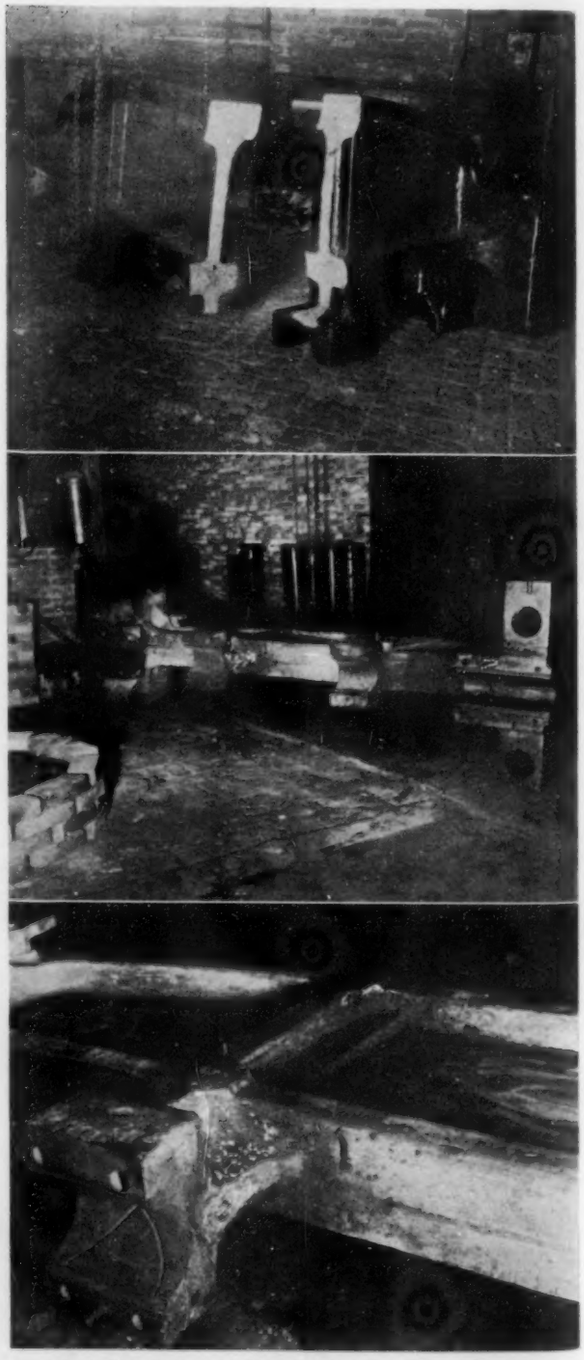


Fig. 7 (Center)—Completed Job Showing Importance of Alignment

Fig. 8 (Bottom)—Close-Up of Completed Weld and Reinforcement

Fig. 9—Cast-Iron Metal Brake Press Frame

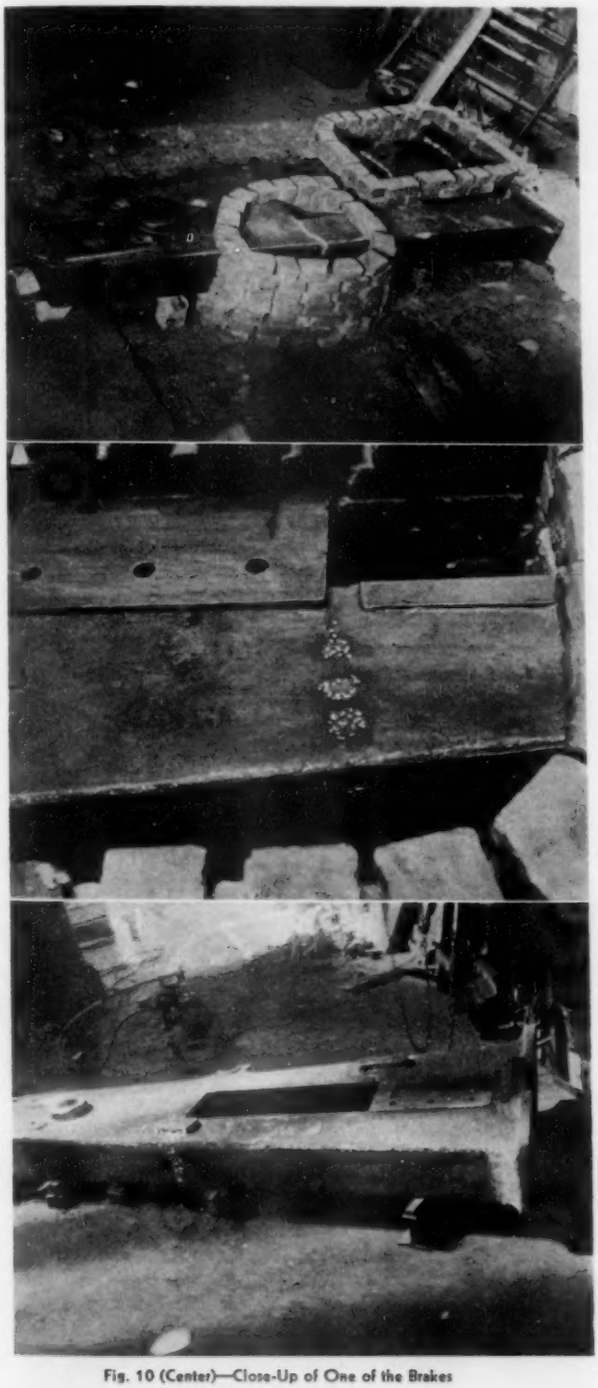


Fig. 10 (Center)—Close-Up of One of the Brakes

Fig. 11 (Bottom)—Completed Job

tions together making it difficult at times to even locate the hair-line crack which remains.

Bronze-welding of cast-iron machinery parts is being used successfully. In using this method it is very essential that the weld first be ground or chipped to a vee and making certain that the base materials are free from any grease, oil or scale at the point of welding. At no time should cast iron, at the point of weld, be greater than a dull red heat. This in itself has caused a great many bronze welds to be unsuccessful.

The illustrations accompanying this paper have been selected as typical plant repairs and each and every one has been successful and still in operation.

Moreover, these illustrations have been selected from many as each one represents an individual problem slightly different. There is one important problem which is common to most of them. That problem is "alignment."

Let me say at this time that we consider alignment and a finished job free of stresses and strains the most important problems that a plant or jobbing shop welder has to contend with and the very problems where we find more welders show a weakness than almost any other. I have come across many jobs in which the weld was first class, thorough penetration, plenty of reinforcement, yet the part failed, because it was so much out of alignment or so full of strains due to improper handling that it could not possibly function for any length of time.

If machine work is necessary, due to distortion, this is very apt to cause the owner to become discouraged with welding, as it adds greatly to the cost of the job.

Figure 1 illustrates a vertical milling machine, which in being moved from one location to another was dropped about 12 feet, due to a defective crane cable. This photo shows the base and only the lower part of the column. When received in the shop, the column was intact and had no breaks but the base had been broken into as many pieces as are outlined by chalk. I'm not so sure but what this might have been one of the original jig-saw puzzles. The column was first set on piers and the various pieces were fitted into their respective positions and tacked in perfect alignment.

Figure 2 shows the job set up preparatory to firing. This will give a better insight into the problem of alignment. Likewise it shows clearly the construction of a preheating furnace, using fire brick.

Figure 3 shows job after it has been fired and welding started. We like wherever possible to use charcoal, because of its evenness and softness. We know many welders will look with scorn on charcoal and refer to us as being out of date. However, I believe I am safe in saying that the welder who thoroughly understands his work, and I say this next in capital letters, THOROUGHLY understands how to handle charcoal, will agree with me. I do not want to give the opinion that we always use charcoal. We do use other means as stated previously.

As you can see we used two torches and three men welding. The third man is not shown, but he periodically relieved the other two.

Figure 4 was taken from same position as Fig. 1, but shows job completed. You might be interested in what transpired between the previous view and this one. Welding was carried on steadily until completed, after which we added only enough charcoal to thoroughly equalize the heat in the base, after which the casting was thoroughly covered with asbestos paper and allowed to cool very slowly. The heating of a casting from the cold stage to welding heat and likewise the reverse operation reducing it from the welding temperature to the cold stage is very important. When cold, casting was removed from the furnace, ground and dressed with a portable electric grinder and returned to customer.

You may be interested in labor and material figures so here they are:

Line up and prepare....6 hrs.—2 men
Heating time.....$6^1/_2$ hrs.
Size of weld approximately 18 ft. of $2^1/_2$-in. welding
Welding time.....17 blowpipe hours, 2 torches, using No. 15 welding heads and 3 welders
Weight.....4000 pounds

Fig. 12—Repair of Broken Metal Brake Press Frame

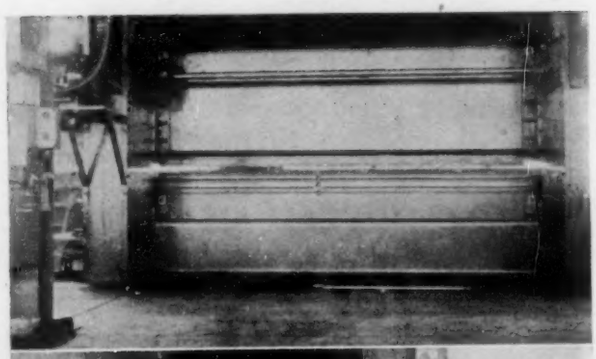


Fig. 13—View Showing Reinforcing Plates

Figure 5 is a radial drill base which was broken along lines shown in chalk. This break was due entirely to a faulty foundation.

Procedure on this job was quite similar to preceding one, namely, preheat, weld and cool. Weld was started in center of break and worked to both ends, using two torches. Material figures on this job were as follows:

Dimensions.....8 ft. x 3 ft.
Welding including ribs on bottom, not shown, 66 in. of 2 in. welding
Weight approximately..3000 pounds

In maintenance welding merely the welding of the broken part is not always the complete answer. As in this job, the break was caused by faulty foundation and to simply weld and replace would only be subjecting the casting to the same conditions which broke it previously, and it would no doubt break again, either alongside of the weld or at the next weakest point. So the foundation should be, and in this case was, put in first class condition.

There are several reasons that may cause a machine part to break in service and we always try to discover the reason which applies in each particular case. We guarantee our welds, but we do not feel that that is enough. We like to explain to the owner of the particular part or plant superintendent that while our weld is guaranteed we cannot guarantee that if the cause of the original break is allowed to remain or to happen again that the part will not break again, of course, outside the weld and urge him, if possible, to eliminate the cause. Whenever possible, we reinforce a weld sufficiently so that some other part of the machine will be the weakest link and not our weld.

Figure 6 is a metal brake press head, which is used in forming metal shapes. Break was caused by overload and extremely low shop temperature.

The size of this break was as follows, 30 in. x $4^1/_2$ in. and the following materials and time were used:

Line up and prepare....4 hrs.—2 men
Welding 30 in. of $4^1/_2$ in., welding not including reinforcing.
Welding time.....11 hrs.—2 men, 1 torch
Gases.....900 ft. (oxygen and acetylene)
Cast-iron rods.....175 pounds
Charcoal.....20 bushels
Weight.....8000 pounds

Figure 7 shows the completed job and it is easily seen that alignment is most important.

Figure 8 shows a close-up of completed weld and reinforcement.

Fig. 14—Cast-Iron Bed for Production Lathe

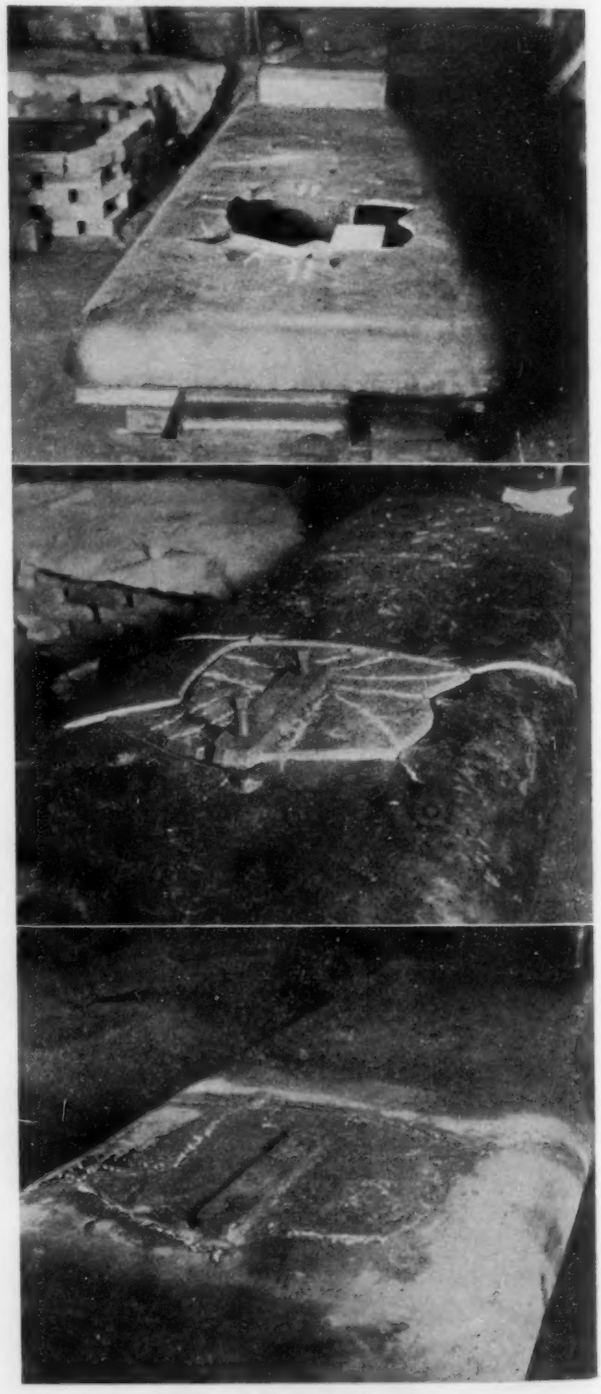


Fig. 15 (Center)—Broken Parts Set in Place

Fig. 16 (Bottom)—Completed Job

Figure 9 is that of a cast-iron metal brake press side frame with two breaks as outlined in chalk inside of each furnace. Alignment was very important on this job.

Figure 10 is a close-up of one of the breaks shown in Fig. 9. I am showing it because it clearly shows our method of tacking broken parts and how the tack materially assists alignment. We will align a job by mechanical means first, then tack the parts together with the electric arc. We find frequently that by mechanical methods we are unable to bring the parts as close together as desirable, but that after tack welding with the arc, the contraction of the arc weld will draw the pieces together, so that as is shown here, only a hair-line crack is visible and frequently even that is not visible.

Figure 11 shows the completed job and also the reinforcing lugs. After the welds are completed to casting level, we shape four fire bricks and build up the space inside, after which we wash and shape lug.

We have found that it does not pay to weld cast-iron welding rods together that are under ten inches in length. These we break up into slugs not over $^1/_2$ inch long, and are used for the purpose of reinforcing casting, after the fire brick mold is set up and a bottom is secured by the welders. The helper then will put in one handful of these slugs and one handful of flux, the welders follow this charge with their welding flames and welding rod to secure a solid weld. This is repeated until the proper height is obtained, usually $1^1/_2$ in. x 2 in. in height. Two No. 15 welding heads are used for this operation, a lug 4 in. x 8 in. x 2 in. high can be built up in about 15 minutes.

The time consumed on this job was:

Line up and prepare....$3^1/_2$ hrs.—2 men
Size of weld.....65 lineal inches of average $2^1/_2$ in. welding
Welding.....$10^1/_2$ hrs.
Gases used.....850 ft. (oxygen and acetylene)
Rods.....165 pounds cast-iron rod
Charcoal.....24 bushels
Size of casting.....10 ft. high x 20 in. wide at top, 40 in. wide at base
Weight.....5000 pounds

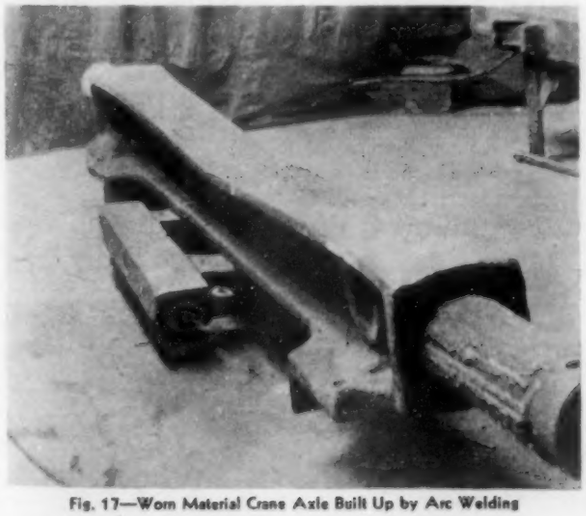


Fig. 17—Worn Material Crane Axle Built Up by Arc Welding

Fig. 18—Repair of Steam Hammer Cylinder

Figure 12 is that of a 390-ton capacity metal brake press frame of steel plate construction, and shows completed job with reinforcing plates in place.

Figure 13 shows a close view of one of the reinforcing plates. The total time consumed in arc welding this job was $45^1/_2$ hrs. for two welders and 55 pounds welding wire. Our problem here was to eliminate any strains that might be left in frame, due to contraction. This was taken care of by setting a screw jack in the front part of the frame or point of finish of weld, it was screwed up to open crack approximately $^1/_4$ in. As the weld progressed the jack was gradually released until weld was within a few inches of the end, at which time jack was removed. At no time did point of weld cover more than 2 in. in length, this space was completely filled in before starting any further.

Figure 14 is that of a cast-iron bed of a single purpose production lathe. This break happened in transit where it must have received a terrific jolt. The part broken out was in approximately ten pieces. This photo shows the bed upside down and does not show slides and runners, which are on the under side as it sets here.

Figure 15 shows the broken part set in place after the many pieces had been bench welded, using cast iron. The original breaks are outlined. This view shows the breaks that remain thoroughly grooved out to the full thickness of the base metal. We did not care to give this a severe preheat as we might injure the slides and runners so we placed an illuminating gas flame on the under side and bronze welded completely around broken section. The broken part was held in place by tacking with the arc.

Figure 16 shows the completed job.

Figure 17 shows a material crane axle worn badly at bearings and built up by the arc welding method.

Bearing size.....$4^7/_8$ in. x 14 in. finished.

Next and last Fig. 18 shows a steam hammer cylinder of cast iron. This is what is sometimes referred to as a surgical operation, because we were forced to cut away the outside wall, to reach the inner wall and after welding the inner crack we then inserted piece cut out and welded same. In this job we preheated the whole base and about half way up the cylinder.

Welding time.....$6^1/_2$ hrs.
Weight.....3000 pounds
Other figures not available.

Some Residual Stress Effects in Static Tension Specimens*

By R. E. JAMIESON†

THIS paper presents some measurements and observations of the effects of residual stresses due to metallic arc welding on mild steel. The work is a continuation of that reported upon at the Fall Meeting of the Society in October 1934.[1]

The object of the present investigation was to observe the behavior of welded plates under static tension load and the variations in this behavior from that of an unwelded plate under similar conditions of average stress. It has been shown that, in the direction parallel to the welds, relatively high tensile stresses are present in the weld metal and immediate proximity, accompanied by compressive stresses of rather lower intensity in the parent metal more remote from the weld. A long narrow plate to which weld metal has been applied along the long edges, would show a distribution of elastic stress at an intermediate cross section of the character shown in Fig. 1. The cross section is in equilibrium, so that total tension equals total compression. The tensile stresses are confined to weld metal and the parent metal in the immediate vicinity. All stresses here referred to are represented by elastic strains.

If such a plate is now subjected to a tensile load in a direction parallel to these stresses, the stress distribution across the plate will be the resultant of the two stress systems and will be the algebraic sum of the stresses so long as the metal behaves elastically. Thus the resultant stresses in the vicinity of the welds will, under this condition, always be considerably in advance of the average stress, and this material will reach its yield point while the stress in the material within the body of the plate is below that value. When this occurs, the more highly stressed material loses all or some of its ability to resist tension until it has stretched to correspond with its yield point strain. As this large deformation cannot occur in the solid plate, the overstressed material transfers its load to the portion which is still elastic, thus reducing the effective cross section. If load-deformation observations are made on such a plate, and a stress-strain curve plotted therefrom, the unit stresses being calculated on the basis of the gross cross section, these stresses will be progressively smaller than the true elastic stresses, and the curve will therefore deviate from the straight line to be expected from a plate free from initial stress. Moreover such deviation should occur initially when the total of applied stress and residual stress at any point in the cross section equals the yield point of the material.

* Contribution to Fundamental Research Committee, A. B. W. To be presented at Fall Meeting, A. W. S., week of September 30, 1935, in Chicago.

† Professor of Civil Engineering, McGill University, Montreal.

[1] "Some Measurements of Residual Stress in Arc-Welded Steel Plates," R. E. Jamieson, JOURNAL OF THE AMERICAN WELDING SOCIETY, December 1934, p. 17.

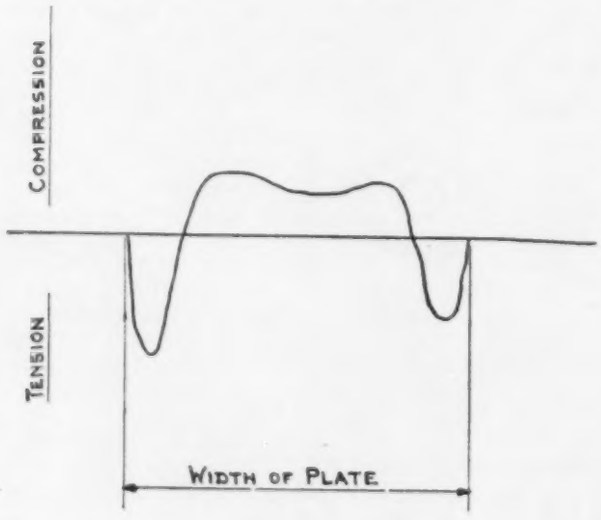


Fig. 1

Specimens

The series comprised five plates of mild steel each $4^3/_4$ in. x $^5/_8$ in. x 5 ft. long, referred to as numbers 1, 3, 5, 6 and 7, and four plates $4^3/_4$ in. x $^5/_8$ in. x 2 ft. 6 in. long, numbers 2, 4, 8 and 9. Plates numbers 1 to 7, inclusive, were machine grooved along both edges, the groove being U-shaped with a cross-sectional area of 0.08 sq. in. Plates numbers 8 and 9 were machined as tensile test specimens, their mid section being reduced to 4 in. in width. All the plates were then stress-relieved at 1150° F. in order to remove rolling and machining stresses. The two short plates, numbers 2 and 4, were cut up and measured after welding to determine qualitatively the distribution of residual stresses in the direction of the welds.

Four long plates, numbers 1, 3, 5 and 6, were welded and tested to destruction in tension. One long plate, number 7, had no welding done on it, but otherwise was treated exactly as were the four long welded plates. The coupons were used to check the stress-strain data obtained from plate number 7.

For welding, the plates were set up at a 45° slope and in order to produce large residual stresses each edge was welded continuously from lower to upper end, filling the groove in a single pass, using a $^1/_8$ in. x $1^1/_2$ in. copper chill bar on each side to prevent burning the edges of the groove. The electrodes were $^5/_{32}$ in., covered, of the type suitable for vertical and overhead welding. The cur-

rent was direct, with electrode negative and work positive, a current of 110–120 amperes and an arc voltage of about 22. The welded plates were not treated in any way after welding. The ratio of weld section to parent section was 5.75%.

Deformation measurements on Plates 2 and 4 were made on a linear comparator, and were confined to a gage length of ten inches at mid-length of plate. Six lines of measurements were taken, and the plates subsequently cut into six strips. Strain measurements on Plates 1, 3, 5, 6 and 7 were made with Martens extensometers on a gage length of eight inches at mid-length of plate. Two pairs of instruments were used, on lines at one inch from each edge of the plate. For reading the large strains occurring after the yield point, a sliding pointer and steel scale on a gage length of thirty inches were used. The Martens extensometers read to 0.0001 in. and the steel scale to 0.01 in., and it was readily possible to estimate these readings to one more place of decimals in each case. Figure 2 shows the arrangement of scale and extensometers. The plates tested to destruction were held in wedge grips in a Wicksteed machine of 100 tons capacity.

Results

The following table gives the recorded measurements of shrinkage and recovery for the several strips of plates numbers 2 and 4. For convenience, both shrinkages and recoveries have been converted into terms of unit stress, using a modulus value of 30,000,000 lb. per sq. in. Only the recoveries represent true elastic stress. In most cases the original measuring marks on the outer strips were obliterated during the welding so that the shrinkage measurements here were not obtained, and are left blank in the table. The minus sign represents shortening and initial compression.

Table I

	Total Shrinkage			Residual Stress		
Strip	Plate 2	Plate 4	Mean	Plate 2	Plate 4	Mean
A		−27600	−27600	+24200	+22200	+23200
B	−23600	−24000	−23800	− 2800	− 600	− 1700
C	−17000	−15500	−12650	−17100	−16100	−16600
D	−11100	− 8700	− 9900	−11000	− 9800	−10400
E	− 6800	− 2400	− 4600	+ 3000	+ 1800	+ 2400
F				+20000	+15800	+17900

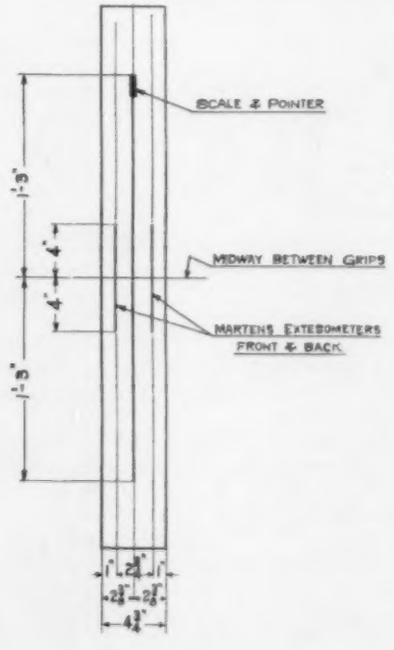


Fig 2

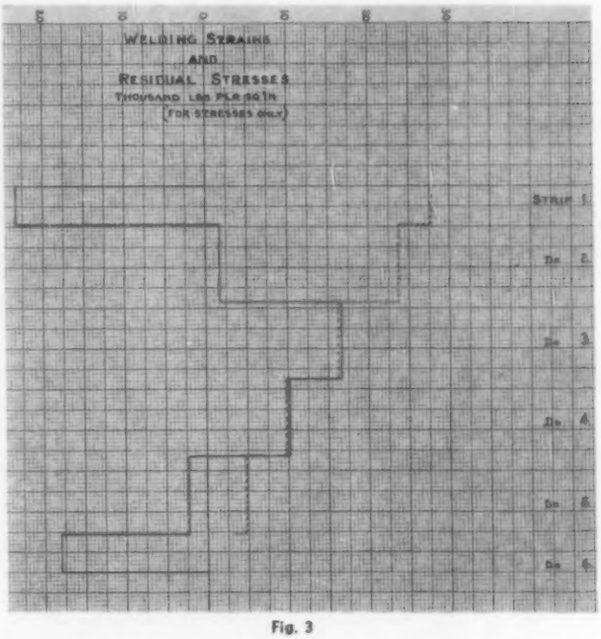


Fig. 3

It will be noted that the results for the two plates are generally in close agreement throughout. The means of both shrinkages and residual stresses are plotted in Fig. 3. The great variation in initial shrinkage from a maximum at one edge to a minimum at the other, may be explained by the fact that one edge of the plate was welded complete before welding was started on the other edge. Unfortunately, no record was kept as to which edge was welded first, but it seems fair to infer that it was the one showing the smaller final shrinkage. The residual elastic stresses vary in accordance with the results of previous tests. The area above the base line represents a total compression force of 17,000 lb. and that below the line a total tension of 13,650 lb. Having regard to the probable errors in the measurements, it may fairly be said that the plates had residual tension stresses of from 22,000 to 25,000 lb. per sq. in. near one edge, and from 16,000 to 20,000 lb. per sq. in. near the other edge.

In Fig. 4 are shown the graphs of the extensometer readings plotted against average applied stress, obtained by dividing applied tensile load by gross cross-sectional area of plate. In computing this area it was assumed that the weld material just filled the grooves. Separate graphs are shown for each gage line measured, and on the graphs for plates numbers 1, 3, 5 and 6 a dotted straight line indicates the mean curve for a normal plate as obtained from plate number 7.

Plates numbers 1 and 5 were partially loaded and then partially unloaded and loaded again, as indicated on the graphs. Plates 3 and 6 were loaded once only. Where material was unloaded and reloaded, it shows in every case the characteristic behavior of overstressed material, the reload graph having a slope substantially that of material which has not been stressed beyond its yield point at average stresses well within the yield point for the normal parent material.

Owing to the use of wedge grips there must certainly have been some eccentricity of applied load in both the planes of the plate. Any eccentricity producing bend-

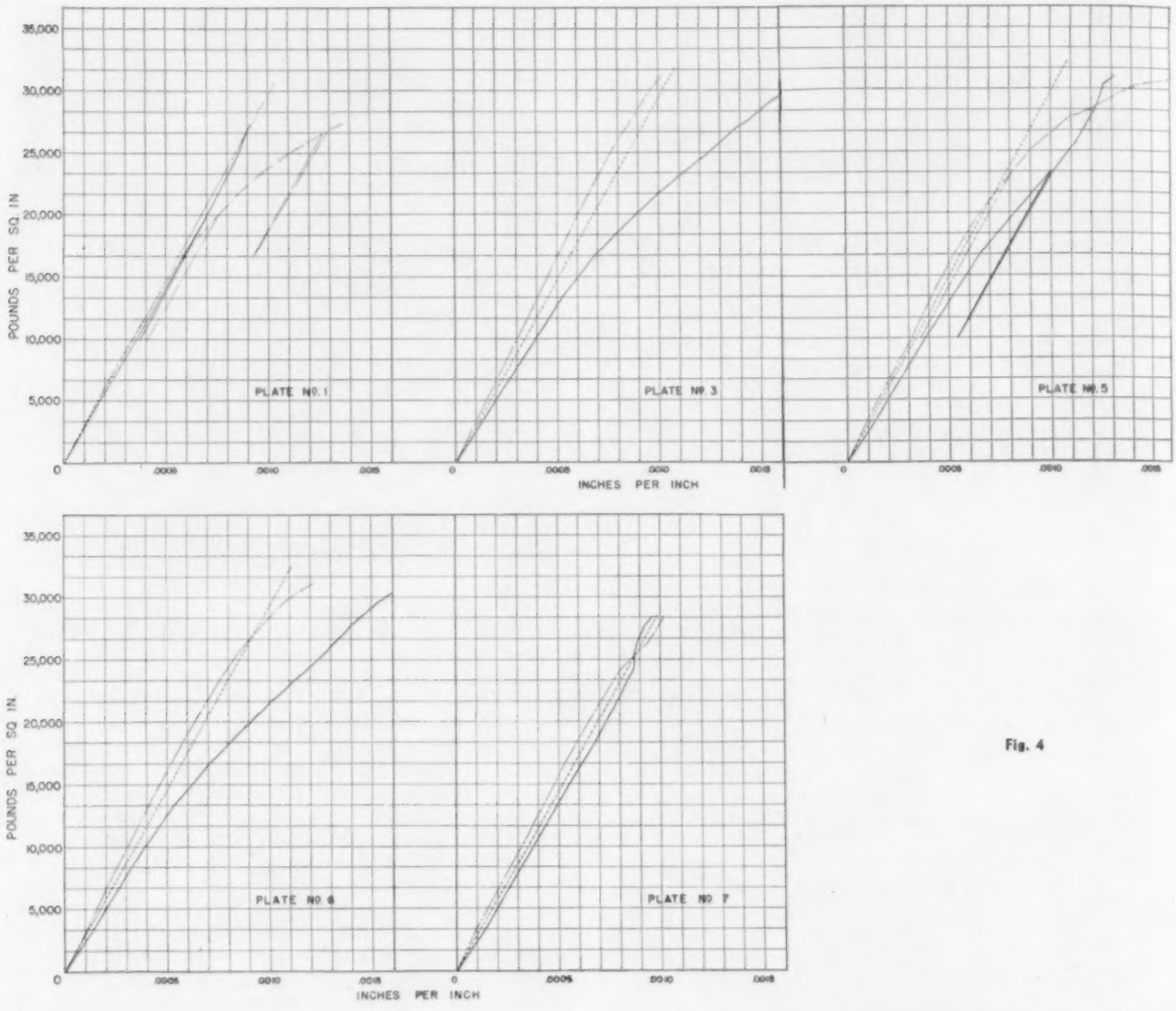


Fig. 4

ing about the long axis of the cross section is corrected for by the recorded means of the readings for a pair of extensometers. On the other hand, any bending about the short axis of the cross section would give rise to a difference of values between these two means, or, on the graph, by a divergence of the graphs for the two gage lines. It is fair to infer that this accounts for the arrangement of graphs obtained for plate 7.

The two gage lines of each welded plate showed great irregularity of strains, as shown on the graphs. Creep was very evident wherever the graph shows a decided decrease of slope, in many cases being noted on one edge while the other edge was still apparently elastic. In every case the yielding was greater on one edge than on the other, and failure took place by tearing, in three cases out of the four starting at the edge which had shown the smaller deformations before the yield.

In Fig. 5 the means of the strains for each plate have been plotted against applied average stresses, and a dotted straight line indicates the mean of the strains read on the unwelded plate. In every case the mean strain of the welded plate shows a progressively increasing divergence from that of the normal material, this divergence being evident at average stresses above 3000 lb. per sq. in.

The average yield value of the normal material as determined from the tests on plates numbers 7, 8 and 9, was 29,700 lb. per sq. in., and the maximum residual stress measured was about 25,000 lb. per sq. in. so that it would appear that the yield point would be reached at some point in the cross section at a superposed stress of about 4700 lb. per sq. in.

In Fig. 6 the graphs of the strains throughout the test of each welded plate are shown, along with the dotted graph representing the corresponding strains of the unwelded plate. These are the readings taken from scale and pointer placed on one face on the center line of the plate. In each case the strain at the yield point was progressive for the welded plates, while it was abupt in the unwelded material. After an increment of load was applied, the load was maintained constant and the strain reading taken only after all the strain for that load had taken place.

The ultimate strengths of the plates expressed in lb. per square inch of original cross section were as follows:

Plate No.	Ultimate Strength
1	49,900 lb. per sq. in.
3	48,300 lb. per sq. in.
5	48,200 lb. per sq. in.
6	45,900 lb. per sq. in.
7	52,900 lb. per sq. in.
Average of welded plates	48,100 lb. per sq. in.

The average ultimate strength of the welded plates is about 9% less than that of the unwelded plate.

The welded plates all fractured initially by tearing from one edge. It is probable that a flaw or irregularity in the welding induced the starting of a crack. The fractures indicated perfect penetration of the welding to the root of the groove. The fractures were irregular, so that measurements of elongation are not very satisfactory, but it was most marked that the elongations were materially less than that of the unwelded plate. The relation was of the order of 12% for the unwelded plates to 33% for the normal material.

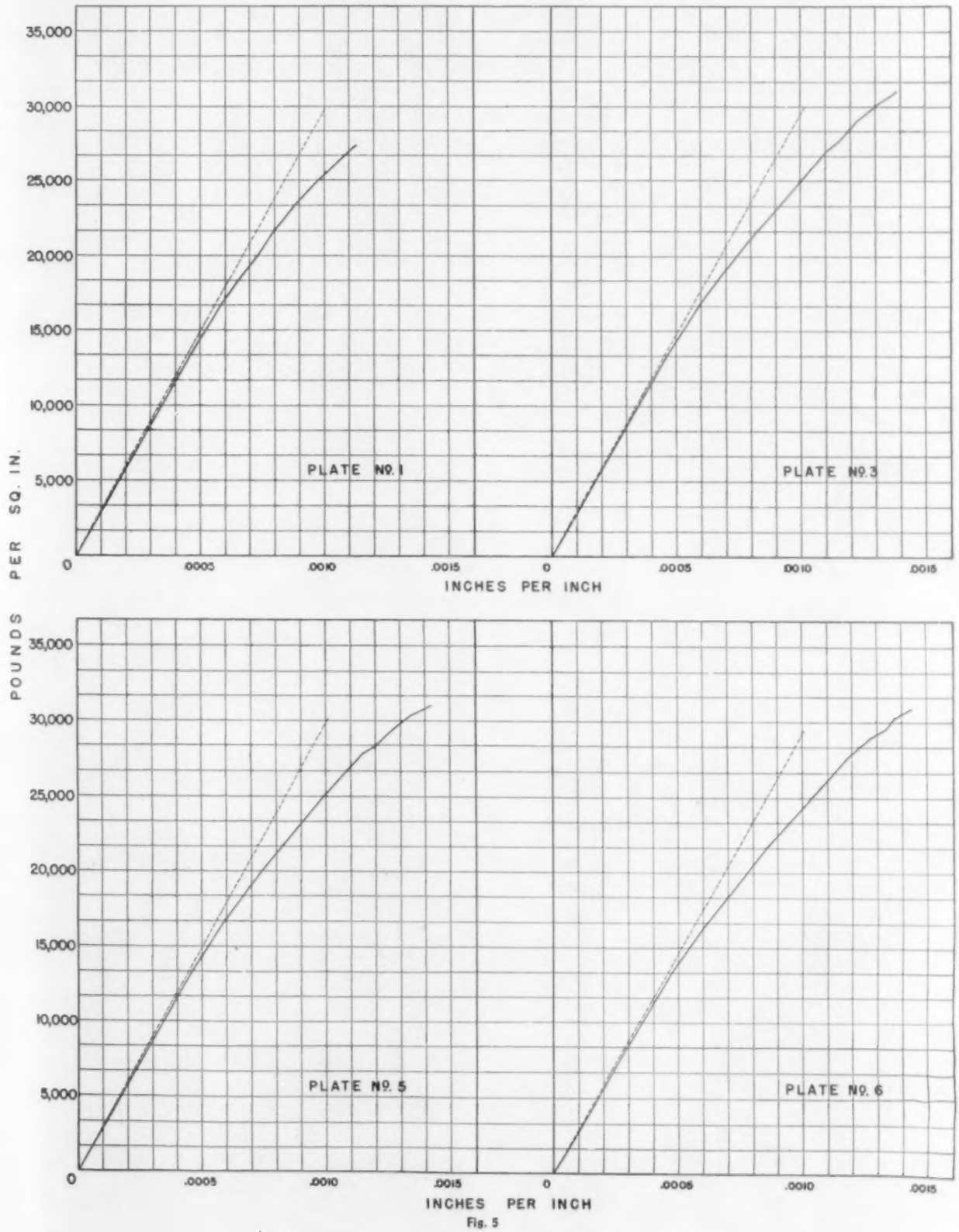


Fig. 5

Conclusions

The presence of the rather high local residual stresses which have been observed exert a marked influence on the behavior of the specimen under static tension loading. The variation from normal, as indicated in the stress-strain characteristics, are in evidence practically from the beginning of loading, thus indicating the presence of localized residual tensile stresses of magnitudes approximating the yield point of the material.

These rather high local initial stresses do not appear to have a serious effect on the strength of the specimen as a

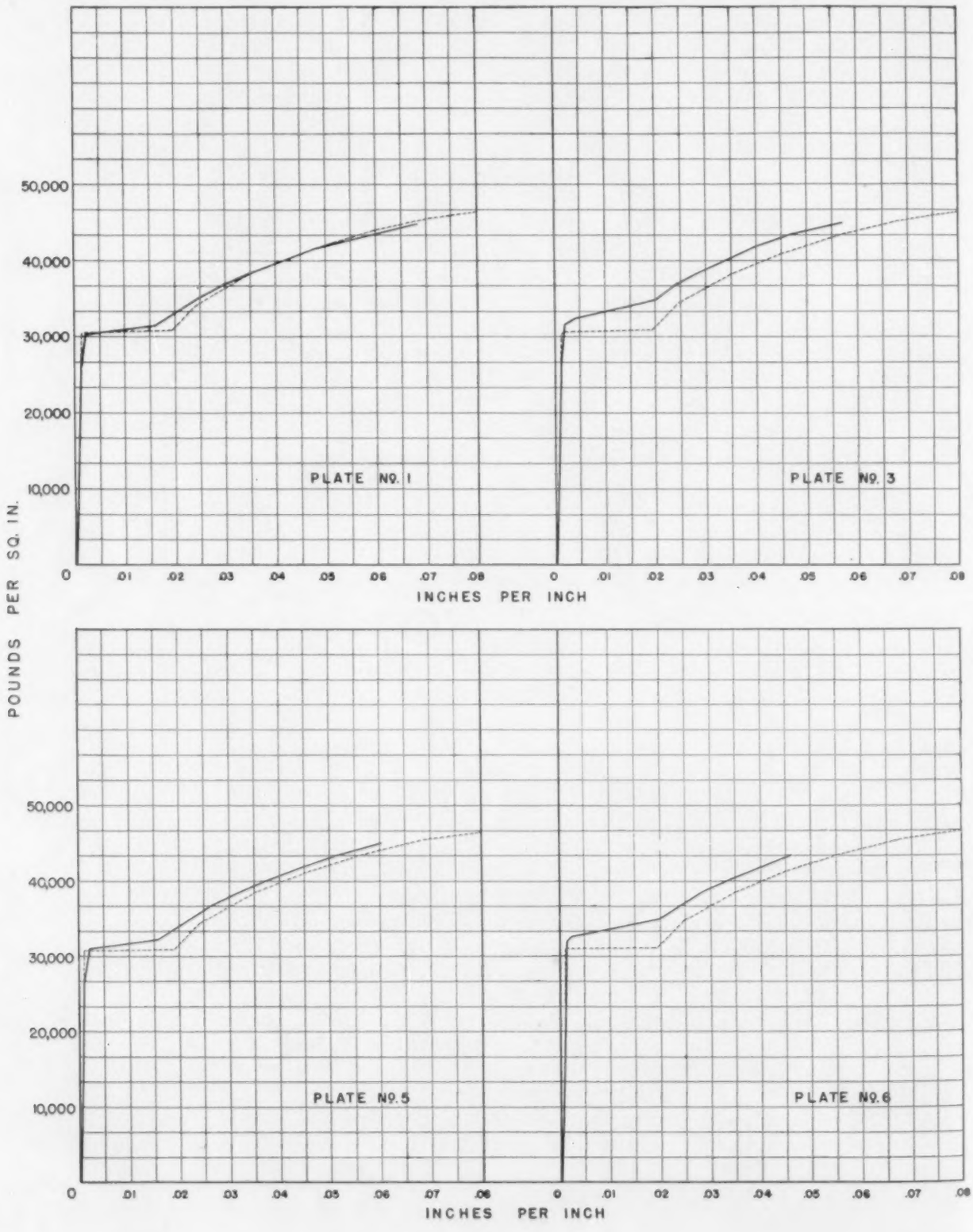


Fig. 6

whole under subsequent static tension loading. Their presence gives rise to substantially larger average deformations than would occur in normal material for a given applied average stress. For example, at 16,000 lb. per sq. in. the excess observed averaged 4% and at 24,000 lb. per sq. in. it averaged 15%. This excess would occur only on the first application of load. During subsequent fluctuations of load up to the maximum value reached, the material would behave as normal material of constant modulus.

The welding appears to raise the yield point and to lower the ductility of the plates. The reduction in ultimate strength, amounting to some 9% on the average, may be ascribed in part to the manner of fracture, which was by tearing. It seems probable that this failure by tearing was largely due to the unequal distortions developed along the edges of the plates, and these inequalities in turn are due to the irregular distribution of the residual stresses across a section.

Planning Arc Welded Bridge Construction

Design of All-Welded Continuous-Girder Viaduct in Kansas City

By LAMOTTE GROVER,† Office Bridge Engineer

EXPERIENCE during the last three years in the use of arc welding on bridge construction and repair work executed under contract by the State Highway Commission of Kansas, indicates that very substantial savings in cost can be accomplished if a carefully planned program is followed. Time is required to train designers and inspectors and also for fabricating shops to train their operators to perform a higher quality of workmanship as well as to effect a certain amount of reorganization and rearrangement or revision of equipment which is invariably required in order to take full advantage of the opportunties offered for economy by welded construction.

Such conditions as usually prevail make it advisable to enter into the use of arc welding for bridges rather slowly. Welding can be used at the start for details involving welded connections of lower responsibility such as floor expansion joints, beam stiffeners and diaphragms, steel deck plating and grillages, bracing, handrails, reinforcing plates for beam flanges, cantilever brackets and built-up rockers and shoes of which the joints are mostly in compression. Then as skill is developed in the shops and inspectors and designers are trained, the use can be gradually extended to more important details and main members.

In order to provide for the occasional training of new operators and at the same time to definitely insure that the highest skilled men are used on the most important work, it is necessary to provide two or three general classifications of welding operators according to their skill as demonstrated by definitely prescribed qualification tests for each classification.

This is the only way in which definite provision may be made for gradually raising the standards of workmanship. Furthermore, it is the only way in which contractors and fabricators can be adequately informed of what

† State Highway Commission of Kansas.

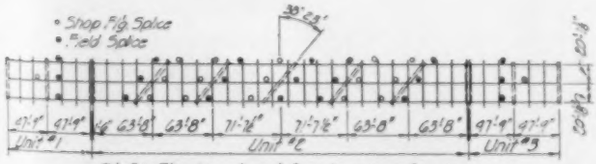


Fig. 1. Pier layout and framing plan of main girders and floorbeams for Fairfax Viaduct (Stringers not shown)

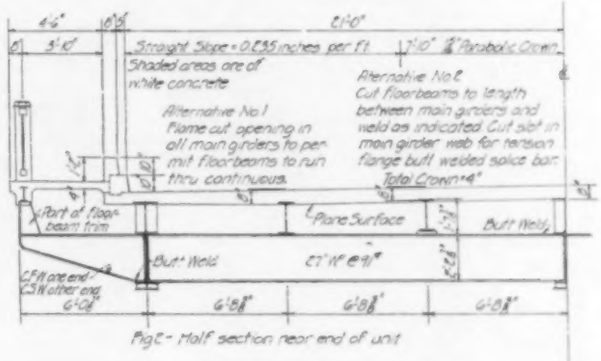

Straight Slope = 0.635 inches per ft.
Shaded areas are of white concrete
Alternative No. 1
Flame cut opening in all main girders to permit floorbeams to run thru continuous.
Alternative No. 2
Cut floorbeams to length between main girders and weld as indicated. Cut slot in main girder web for tension flange butt welded splice bar.
Total Crown = 4"
Part of floor beam trim
Plane Surface
Butt Weld
Butt Weld
CF fit are end - CSW other end
6'-0"
6'-8"
6'-8"
6'-8"

Fig. 2 - Half section near end of unit

standards of workmanship they must attain in order to execute more important classes of welded construction in a satisfactory manner. It has been found that no amount of specification clauses, however severe they may be, will bring contractors and fabricators to the realization of the limitations of their organizations until they are shown the definite classification that can be attained by their operators at the present state of their training and with the equipment with which they are provided.

For a more detailed discussion of these problems of shop control and qualification of operators and electrodes, as well as for illustrations of some of the minor welded details that have been mentioned, the reader is referred to an article by the writer in the August 1935 issue of the *Better Roads* magazine, entitled "Control of Structural Welding Work," which was presented at the recent Welding Conference at the University of Kansas.

The most attractive field for economy of arc welding lies in the construction of built-up girders, and the details of design and construction procedure are less complex in this field than in the case of welded truss bridges. There are many examples of all-welded girder bridges which have been studied to develop the best principles of design and construction procedure. The German State Railways alone have more than two hundred welded girder bridges in service and they, as well as many other organizations, have conducted very extensive programs of research study along with observations of structures under service in order to develop the best standard practices for such work. This type of construction is therefore the logical field to enter as soon as sufficient experience has been attained by an organization through

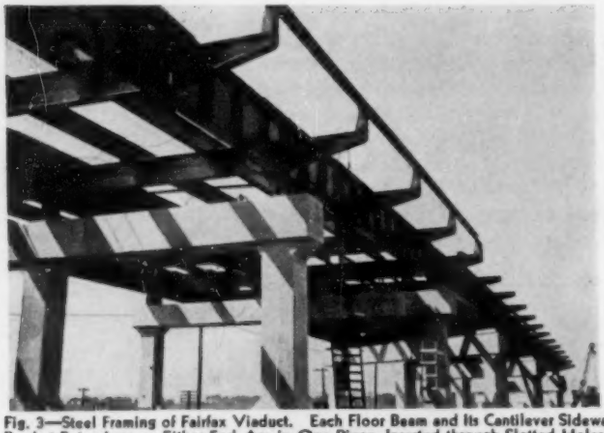


Fig. 3—Steel Framing of Fairfax Viaduct. Each Floor Beam and Its Cantilever Sidewalk Bracket-Extensions on Either End Are in One Piece, Inserted through Slotted Holes in Main Girders and Fillet Welded to Girder Webs

the use of welding for more or less minor details and members.

Fairfax Viaduct in Kansas City

In order to illustrate some of the best current practices of design and construction procedure for such work, the general design features will be presented for an all-welded continuous-girder viaduct of 595-foot total length and 42-foot roadway with two 3 ft. 6 in.-sidewalks, which design was prepared for the "Fairfax Viaduct" on the North Seventh Street Trafficway over the rights-of-way of the Union Pacific and Missouri Pacific railways in the north part of Kansas City, Kansas (see *Engr. News-Record*, Oct. 19, 1933, Vol. 111, No. 16). The structure involves a central six-span continuous skewed group of the following approximate span lengths, 64-foot, 64-foot, 72-foot, 72-foot, 64-foot, 64-foot, squared at the ends of the group and flanked at each end with a double 48-foot span continuous group, all supported by reinforced concrete pedestal-type piers and abutments (Figs. 1 and 3).

Bids were received for two alternative designs, one all-welded and the other with riveted construction for the main girders, three lines of which extended throughout the length of the bridge. The details of the rolled floor beams and stringers as well as their welded connections were substantially the same for both alternatives. Due chiefly to the lack of experience among fabricators within the range of competition and their hesitancy to undertake as large an all-welded project as this for their first major venture, involving approximately 376 tons of steel exclusive of the welded steel handrail, bids were substantially the same for both alternatives despite the 33-ton saving of 15% of the weight of the main girders offered by the all-welded alternative; and the contract was let with provisions for riveting the main girders.

The riveted details followed usual precedents and only the details for the all-welded design will be described. Some limitations were imposed by the uncertainty that full reliance upon welded details of main members and connections would be approved by the U. S. Bureau of Public Roads under whose jurisdiction the work is being constructed as an NRS project; and it was desirable to receive bids upon one alternative that would surely be approved.

Under these circumstances, each rolled floor beam was detailed in one piece throughout its length, to be inserted and carried through slots or holes in the webs of the three main girders, flame cut to the approximate profile of the floor beam section. The exterior portions of these floor beams which extend beyond the outer main girders were coped on the under side to form cantilever brackets of more pleasing appearance than the full depth section and the waste was utilized to make supports for the longitudinal sidewalk girders (Fig. 3). Curved bottom flange plates for the cantilever brackets were fillet welded to the coped web and butt welded to the bottom flange of the full depth section. This could be done in the shop for one end of each floor beam but obviously had to be deferred for the other end till the floor beams had been inserted through the slots in the main girders during erection (Fig. 2).

The stringers are laid upon bearing blocks of different thicknesses as required to provide a crown in the floor slab. They are designed as continuous beams throughout their lengths between floor expansion joints at the ends of each continuous group of main girder spans.

The main girders of the all-welded design are built up from a web plate of $^3/_8$-in., $^1/_2$-in. or $^5/_8$-in. thickness, 50 in. deep for the interior girders and 48 in. deep for the exterior girders, and two solid flange plates varying from 16 in. x $^3/_4$ in. to 16 in. x $2^1/_2$ in., the webs and flanges being joined with four $^5/_{16}$-in. continuous fillet welds which were usually much more than ample for stress requirements, except for a short section over the heaviest reaction where $^7/_{16}$-in. fillet welds were specified.

Butt welded splices for the flange plates were provided along with full and definite notes and specifications for making them properly. All intermediate stiffeners were of 7-in. x $^7/_{16}$-in. bars and the stiffeners under the floor beams and over the main girder reactions varied from $7^1/_2$-in. x $^1/_2$-in. bars to $7^1/_2$-in. x 2-in. At all splices in the main girder webs, the stiffeners were made of $14^1/_2$-in. x $^1/_2$-in. plates extending across the width of the flanges. The two abutting ends of the web were spliced by joining them to this transverse stiffener plate on either side with fillet welds in each of the four corners equal in size to the thickness of the web plate (Fig. 4).

Although only a part of the welded details have been actually constucted on the Fairfax Viaduct to prove their practicability, most of the other details were used in the construction of two full-size built up welded girders that were tested to destruction with two 200-ton jacks by the state highway commissions of Kansas and Missouri at the Kansas City Structural Steel Company in the fall of 1933. The construction of these girders offered a very favorable opportunity to determine the best welding procedures. After the tests had been completed, the heavy flange butt welds as well as other important joints were cut up into laboratory test specimens in the case of the

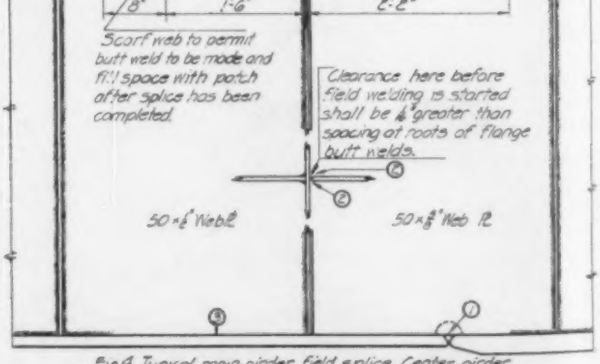

16×1⅛" Fig. 12
16×2⅛" Fig. 12
8"
1'-6"
2'-2"
Scarf web to permit butt weld to be made and fill space with patch after splice has been completed.
Clearance here before field welding is started shall be ⅛" greater than spacing of roots of flange butt welds.
50×⅜" Web
50×⅜" Web 12

Fig. 4 Typical main girder field splice. Center girder splice nearest to middle pier showing girder ends ready for field welding. Numbers encircled indicate sequence of field welding.

Kansas girder, which operation afforded a very complete examination of the welds. A description of the Kansas girder test will appear in an early issue of the *Engineering News-Record*.

Further confidence in the details as specified for the Fairfax Viaduct was gained by presenting the typical details of design and welding procedure to several outstanding engineers and technicians in this country for comment and approval, as well as to several in foreign countries who were intimately acquainted with practical construction and research work relative to welded bridges. Under these circumstances it is felt that the design and welding provisions can be presented as conforming to the best current internationally accepted principles of welded girder bridge construction.

Details of Preparation and Welding Procedure

Since the exact details for the preparation of material and for the procedure of welding affect the cost of construction to a very large extent, it is considered necessary to supplement general specifications, however complete and adequate they may be, with sketches and notes on the plans to clearly indicate the interpretation of the specifications as they pertain to the various types of welded joints and connections, in order to avoid serious controversy and perhaps the payment of extras during construction.

All butt welds were shown to be of the double V type, or double U type as an alternative, except those to be executed in the field, where the difficulties of depositing metal in the overhead position were considered to more than offset the advantages of balanced deposition, especially with the limited amount of experience in overhead welding that has been gained by most of the steel fabrication and experience in overhead welding that has been gained by most of the steel fabrication and erection organizations. The preparation of the edges and the approximate number and sequence of runs of weld metal were shown for a typical example together with instructions relative to other plate thicknesses (Fig. 5). All of the important shop welds were specified to be made in the flat position with electrodes specially adapted to the making of welds of very high ductility and high resistance to impact and repeated stress. Specifications for all other electrodes used on the work contained sufficiently high requirements that they could be met only with high grade heavily flux-covered electrodes.

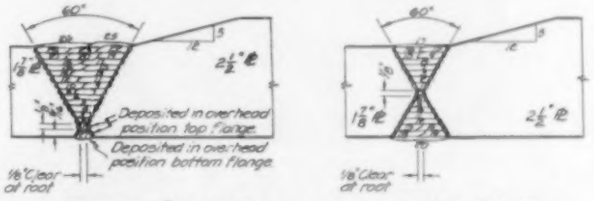
All web and flange plates were specified to be universal mill plates and all edges to be welded either with butt welds or fillet welds were specified to be either rolled edges or flame cut, the welding of sheared or rough finished edges being prohibited because of the embrittling effect of applying heat after the serious cold working and tearing that results from shearing, rough sawing or rough finishing. In Fig. 6 are given the provisions that were specified for clearances at fillet welded joints.

All shop splices of component parts were required to be made before assembling the parts, in order to provide free contraction. The permission of the Engineer, given expressly for each particular joint, was required for work to be done at a temperature below 50° F. so that the most favorable conditions for reducing shrinkage stresses could be demanded, especially in the case of the field welded girder splices. Provisions were made for requiring the peening of every run of weld metal in the main butt welded splices, at the option of the Engineer; but it was not planned to use such peening unless it proved advisable to do so during construction and until a carefully controlled procedure had been developed with the equipment available and had been proved satisfactory by making trial joints and testing them.

The ends of all butt welds for flange splices were specified to be extended out onto small pieces of steel plate temporarily tacked to each edge of the flange plate, these extensions to be removed subsequently by flame cutting and grinding. In this way the end portions of the butt welds were to be discarded because they usually contain defects caused by starting and breaking the arc at the edge of the plate.

Main Girder Field Splices

Each span together with adjoining parts of adjacent spans was specified to be assembled complete with floor beams in place before shipment to the site and the joints



Maximum size of electrodes permissable for runs 1, 2, 3 & 27 shall be 5/32" diameter. Maximum size for all other runs shall be 3/16" diameter.

FIELD FLANGE SPLICE

Maximum size of electrodes permissable for runs 1, 2, 3, 4 & 5 shall be 5/32" diameter. Maximum size for all other runs shall be 3/16" diameter.

SHOP FLANGE SPLICE

Fig 5

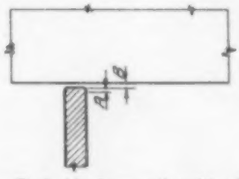


Fig 6 Maximum allowable clearance "B" at fillet welded joints = 1/4" in. except when parts are specified to be ground to bear. When U.M. plates are used and rounded edge extends more than 3/32" (Dimension "A"), or if A+B exceeds 3/8", an initial run shall be made with a 5/32" electrode. Leg dimensions of fillets shall be increased over nominal size by the amount of clearance "B."

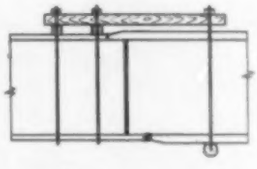


Fig 7 Main girder field splice to be supported freely as indicated while being welded in the field.

properly fitted, and erection cleats, clips and match marks attached or made with parts assembled. All main girders and floor beams of any continuous unit were required to be erected complete in place before any of the field welding was performed in that unit, and all clamps, temporary bolted cleat connections, etc., were required to be loosened sufficiently to avoid restraint while the main girder splices were being welded.

In order to provide the necessary freedom for movement due to contraction during the welding of the main girder field splices, provisions were required for the free support of the adjacent girder ends at the splice being made, by means of a jig as sketched in Fig. 7, and likewise for the support of the next main girder field splice in the direction of progress; i.e., toward the end of the group. The sequence for making the various butt and fillet welds and the clearances involved in the main girder field splices are indicated in Fig. 4. The general sequence of welding the field splices and the floor beam

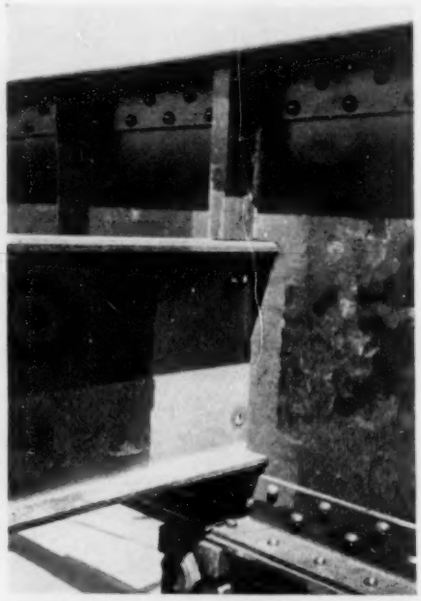


Fig. 8—Floor Beam Inserted through Slotted Hole Cut with a Gas Torch in Web of Main Girder. Note Flame Cut Holes for Drift Pins. Space Still Remains for Inserting Reinforcing Plates That Will Be Welded Flat against Web of Floor Beam to Carry Main Girder Reaction between Heavy Bar Stiffeners of Main Girder Above and Below the Floor Beam

and stringer connections was specified for every group as follows:

"The field welding of splices and connections shall begin with the main girder splices nearest the fixed bearing pier of the group and shall proceed toward the ends of the group. The floor beam connections between the center fixed-bearing pier and the farthest completed splices in the main girders may be made as the welding of the main girder splices progresses and they shall be made proceeding from the fixed pier toward the ends of the group. The stringer splices and connections may be made at any time after the connections have been completed for the floor beams that support them."

Floor Beam Connections

Next in order of importance and interest to the splices of the main girders and their parts, are the details of the floor beam connections. These are rather unusual although not without precedent. While the general scheme for the floor beam framing was adopted somewhat out of a consideration for placing less responsibility upon the welded connections, the details are thought to be quite clean cut and acceptable under any circumstances.

The holes slotted in the webs of the main girders to accommodate the cross section of the floor beam were cut to dimensions enough larger than those of the floor beam cross section plus web reinforcing plates where they were required, that erection difficulties were avoided, even though there was some variation in the depths, flange widths and other dimensions of the floor beam section. Flat plates not less than $^5/_{16}$ in. thick were used to fill in the extra clearance and to wedge the floor beams down tightly upon the bearing stiffeners below them, as well as to force the web of the floor beam into a close contact with one side of the slot in the main girder web.

These filler plates were then welded to the flanges and webs of the floor beams and also to the edges of the slots in the girder webs, so that after completion the entire connection was completely encircled and sealed against corrosion. As evident in one of the illustrations (Fig. 8), three holes were cut for drift pins in the web of the floor beam at each connection, two on one side of the main girder web and one on the other side. The fact that the floor beams had to pass through the slots prevented the use of temporary cleats, bars or other aligning devices for spacing and holding the main girders at the proper locations on the floor beams. However, the cutting of these drift pinholes was neatly done with a portable gas cutting machine and any extra handling of the floor beams thereby avoided.

An alternative detail was investigated for the floor beam conections, in which the floor beams would have been cut to exact length between main girder webs less clearances for the spacing at butt welded connections. This detail was not regarded with as much favor as the other because the clearances and beveling of edges necessary to provide for the proper field welding procedure would have resulted in heavy concentrations of weld metal that might have caused difficulty in avoiding high shrinkage stresses and would have been expensive from the standpoint of preparation of edges as well as increased amount of weld metal.

A third suggested alternative, shown at the right-hand edge of Fig. 2, is perhaps the best, if no undue limitations are placed upon the use of welding by the prevailing regulations or by lack of experience. In this detail, the compression flange and the web of the floor beam are squared and fillet welded to the main girder web on either side. A slot is cut in the main girder web on line with the tension flange which is spliced by being butt welded on either side to a bar inserted through the slot and of the same size as the flange. The clearance at the fillet welded web and compression flange splice should be made slightly greater than the spacing at the root of the butt weld in the tension flange splice on both sides of the main girder, and the butt welds should be made first to permit free contraction.

Such a connection and flange splice would be appropriate at the intersection of the floor beam with the interior girder of a structure such as the Fairfax Viaduct. At the exterior girders, where the floor beam moments to be transferred to the brackets are relatively small and the girders are not very stiff against torsion, usually it would not be objectionable to introduce eccentricity into the tension flange splice. The entire section could be squared and butted against the main girder web and fillet welded to it. Then a slot could be cut just above the upper or tension flange of the floor beam to accommodate a splice bar that would be lap welded to the floor beam flange on the one side of the main girder and to the top flange of the cantilever bracket on the other side.

Fig. 9—Welded Structural Steel Floor Expansion Devices. The Two Parts with Serrated Edges Were Flame Cut from the Same Steel Slab. When Set Up with Their Tops Flush with the Floor Slab They Will Fit Together Again and Be Spaced Apart to Allow for Expansion

Minor Details

All stiffeners for the main girders were shown to be coped at their inner corners to clear the fillet welds between webs and flanges in order to avoid the cumulation of shrinkage stresses where there would otherwise occur an intersection of six lines of fillet welds. These copes were specified to be large enough to provide clearance for returning the stiffener welds around all corners at their terminations where stress concentrations are highest.

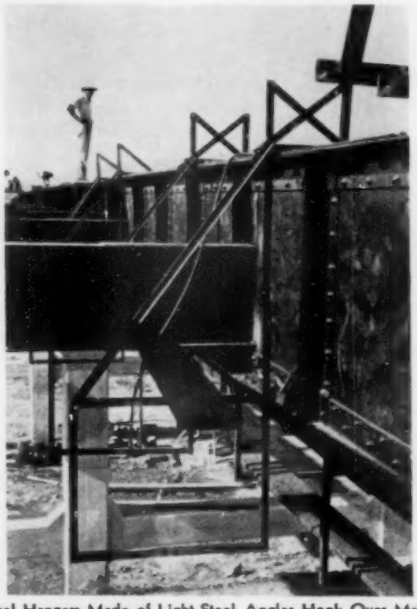


Fig. 10—Novel Hangers Made of Light Steel Angles Hook Over Main Girders and Support Scaffolding at Either of Two Elevations to Permit Easy Access for Welding All Parts of Floor Beam Connections

The stringer splices were designed to facilitate the field welding as much as possible, using lap welded web splice plates and fillet welded straps for splicing the top flanges. This is not considered a satisfactory type of splice for main girders of a structure subjected to dynamic loading, but the stringer splices always occur over a floor beam which supports both of the adjacent ends, and the top flanges are embedded in the concrete floor slab which shares the stress somewhat and discourages stress concentrations around the stringer splices. Under these circumstances it was considered satisfactory to sacrifice the best form of joint in the interests of economy and avoid cutting the stringers to exact lengths and carefully preparing their ends as would have been required for butt welding.

A small amount of lateral bracing was provided over the middle pier. The rockers and shoes were all built up of flat plates and slabs fillet welded together, and the handrail was of rugged design and all-welded. The built-up welded floor expansion devices are shown in Fig. 9.

Unit Stresses

The allowable unit stresses for the welds were rather low: 9000, 10,000 and 12,000 lb. per sq. in., respectively, for shear, tension and compression, to conform to the provisions of the Tentative Specifications for Arc Welding Metal Bridge Structures of the American Association of State Highway Officials. However, in this type of construction this is not a serious economical handicap because the fillet welds are made continuous to seal the joints against moisture and corrosion. For instance, the web to flange welds could have been made $^3/_{16}$ in. size throughout most of the length of the main girders without overstress, and in fact these smaller sizes have been used successfully in foreign countries with flange plates as thick as $2^1/_2$ in., and may be expected under such circumstances to be used in our bridge construction when more careful control is generally established to warrant their recognition in specifications sponsored by national organizations. The smaller amount of heat applied with these small sizes of welds lessens the tendency toward distortion.

With the prescribed unit stresses, it was of course impossible to develop the full strength of the main girder flanges at their splices; but all splices can be placed conveniently at points of minimum moment where the actual maximum stresses are far below the allowable.

Experience and tests seem to have definitely proved that any excessive reinforcement of butt welds, either with welds metal or with fillet welded straps, actually weakens the joint as a whole under dynamic repeated loading, due to the stress concentrations that are set up in the base metal as well as in the welds at the points of comparatively abrupt change in section.

Conclusion

Arc welding procedures have been developed through actual experience and research investigation to the point where they can be employed with safety for more complex bridge construction, such as the Vierendeel truss bridges that have been constructed recently by the Belgian Administration of Bridges and Highways, when good control is maintained.

Many of the fabricating shops throughout the country have used arc welding to quite a considerable extent for a number of years, but comparatively few of them have shown the progress necessary for extending the use of welding into the more complex details of bridge construction with both safety and economy. This state of progress will be attained only when the engineers who design and supervise such construction set up a system that will require fabricating shops to organize their welding departments under adequate engineering control and training to use the best modern procedures.

Special acknowledgment is made of the kindness of the following welding engineers and technicians who have reviewed the general design features for the Fairfax Viaduct and have offered valuable comments and suggestions relative to the details: Andrew Vogel, Welding Engineer of the General Electric Company; E. W. P. Smith, Consulting Engineer of the Lincoln Electric Company; E. P. S. Gardner, Chief Engineer of the Quasi-Arc Company Ltd., London; and M. Charles, Chief of Works Organization, La Soudure Électrique Autogène (Arcos), Brussels.

The Fairfax Viaduct all-welded design was prepared by George L. Epps and George W. Lamb under the direct supervision of the writer and his assistant, Paul G. Martin. H. D. Barnes is State Highway Engineer, O. J. Eidmann, Engineer of Design and R. B. Wills, Engineer of Construction for the State Highway Commission. Direct supervision of the shop inspection was by L. R. St. John, Materials Inspector, the field construction being supervised by C. O. Baker, Resident Engineer. The fabrication and erection of the structural steel were executed by the Kansas City Structural Steel Company, for whom L. L. Cramer is welding supervisor.

Preventing Distortion of Longitudinal Seams in Welded Pressure Vessels*

By J. T. PHILLIPS†

If the question "What is the greatest problem in welding?" were asked a group of welding foremen, the majority of the answers would surely be distortion. Also, there would be many stories of sad experiences due to this ever-present problem. The exasperating part is that after spending extra time in producing excellent welds in a job of close tolerances, a foreman may find that his work is only the beginning of a series of maddening attempts to bring his product within the prescribed tolerances.

The subject of distortion due to welding is so broad that the writer will confine himself to ways of preventing excessive warping of cylindrical pressure vessels while welding the longitudinal seams. This applies to boiler drums and sections of longer pressure vessels which are commonly re-formed after welding these seams.

Many companies have made it a standard procedure to re-form all cylindrical vessels having welded longitudinal seams. This re-forming is done either hot or cold, depending largely upon the plant equipment. In some cases the manufacturer, considering the effect of this operation on the vessel as a whole, has a very decided opinion as to which is the better method. Re-forming by hot rolling the cylinders is rather expensive and usually an objectionable amount of scale is formed, yet this operation does not leave one in doubt as to a fractured weld.

The fabricator who re-forms his cylinders cold has a vessel free of excessive scale and his cost will probably be much lower. However, he cannot conscientiously apply enough pressure on a welded seam to actually reset it cold, when the plate thickness is $1^1/_4$ in. and over, without first stress-relieving the cylinder. This is especially true in a cold shop, and the purchaser of the vessel would be justified in requesting that such seams be X-rayed after this operation if it were not the shop's practice to do so.

In some shops the double "U" groove is used to equalize the strains set up by welding and this method usually produces a cylinder well within the A. S. M. E. Boiler Code and A. P. I.-A. S. M. E. Code tolerances. However, it handicaps the welder of the first bead and requires much care in chipping out the poor metal from the other side of the plate preparatory to welding it inside. Also half the welder's time is spent welding inside the vessel and this must be done by hand welding in average size vessels, making it far more expensive than the single "U" method of welding—especially where the shop can use automatic machines for all the beads except the customary two which are deposited from the inside by manual welding.

The Foster Wheeler Corporation has been using the single "U" groove method of welding since its Cartaret, N. J., plant entered the welding field, and it is a rare occasion when a welded cylinder has to be returned to the rolls for rerounding, notwithstanding the fact that the above company has one of the largest sets of rolls for this type of work in the country. The out-of-roundness seldom exceeds one half of the tolerances allowed by the Codes, and the extra time taken to prevent the usual sinking inward of the seam during welding is much less than the time taken in re-forming a distorted cylinder. The extra expense of stress-relieving the thicker walled

* Paper to be presented at Fall Meeting, AMERICAN WELDING SOCIETY, week of Sept. 30, 1935, in Chicago.

† Supt. Boiler Shop, Foster Wheeler Corporation.

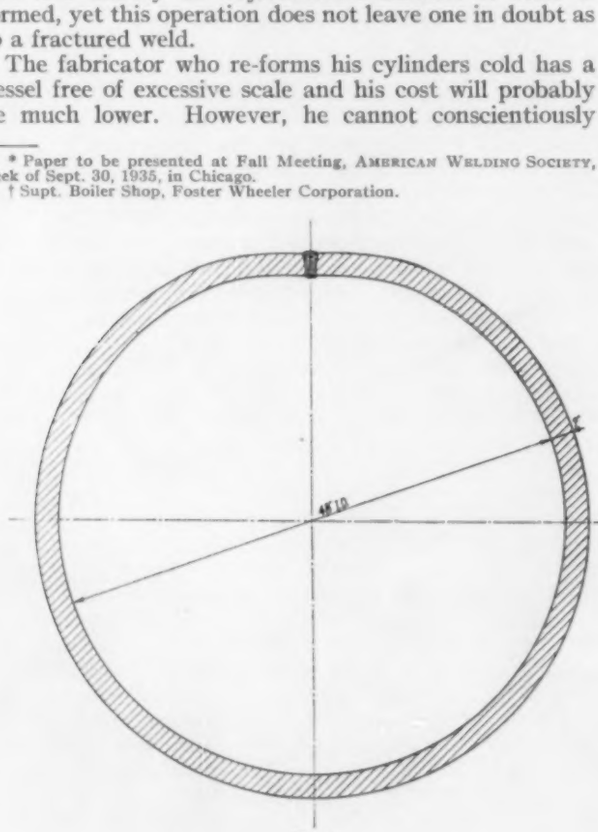


Fig. 1

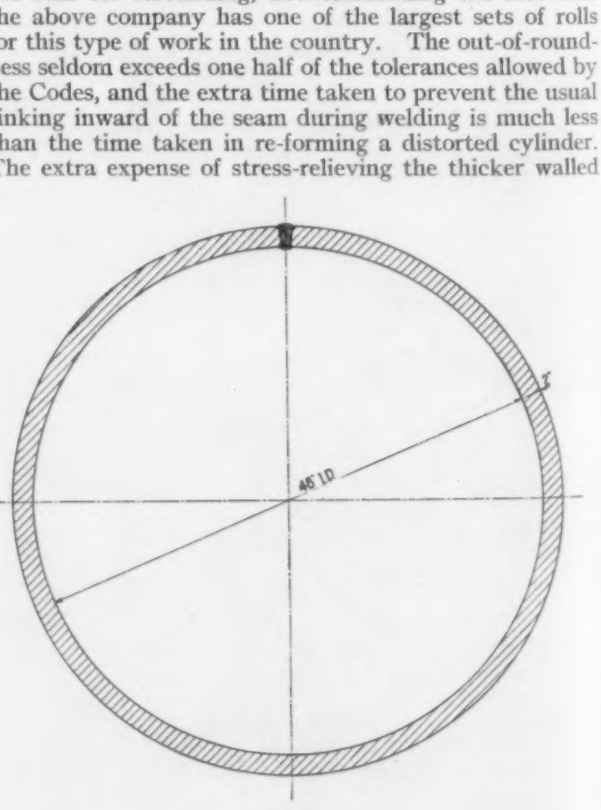


Fig. 2

Fig. 3

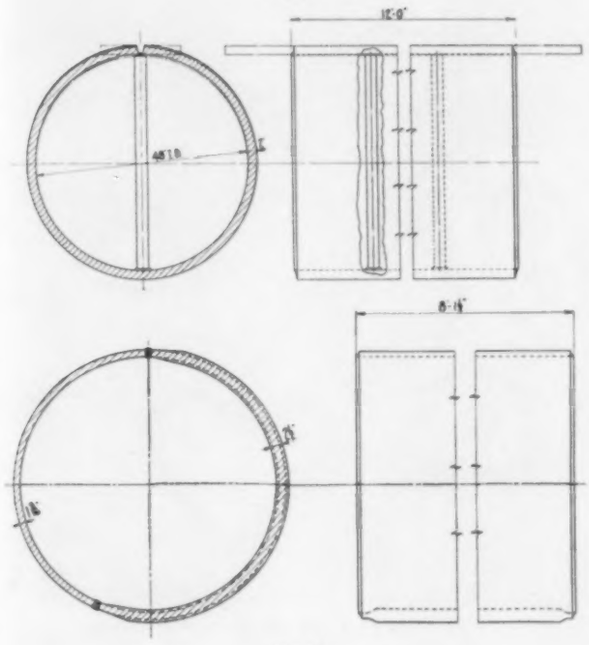


Fig. 4

cylinders prior to re-forming cold is eliminated, and instead of the seam distorting as in Fig. 1 (a familiar sight in welding shops) the cylinder is uniform in radius at the welded joint itself, as in Fig. 2.

The general method which we are successfully using is to distort the cylinder at the seam by the use of supports as in Fig. 3, making the inside diameter at the seam greater than the specified diameter prior to welding. We prefer that the edges of the plate be formed to the same radius as the rest of the cylinder rather than to a slightly larger radius, which is sometimes done to allow for distortion, for we have found that better results can be obtained in this way. Also if the first cylinder of a group is not as round as expected after welding, the length of the supports can be varied slightly to obtain the desired result and used on all subsequent jobs. The range in plate thickness most suitable for this method is from one to two and a half inches.

As an example of the above method a drum shown in Figs. 2 and 3, 48 in. I. D., 2 in. thick and 12 ft. 0 in. long, was welded as follows:

The drum had a $^1/_4$ in. $\times$ 1 in. steel backing bar tack-welded to the under side of the longitudinal seam and four bars welded across the seam inside to hold the edges in line and to prevent them from spreading apart. Then two men with fifty-ton jacks placed four supports inside the vessel, bearing directly on the backing bar. These supports held the drum $^1/_2$ in. out-of-round as in Fig. 3, the inside diameter at the seam being $48^1/_4$ in., and at right angles to the supports $47^3/_4$ in.

The seam was then welded approximately three quarters of the way to top of groove, the supports removed and the inside of seam chipped and welded in the usual way. At this point the drum checked from $^1/_8$ in. to $^3/_{16}$ in. large in diameter at the seam. The outside welding was then completed and the drum again checked and found to be $^5/_{32}$ in. out-of-round at each end and $^1/_{16}$ in. out in the middle. You will notice that the supports are from 15 in. to 18 in. from each end because of the tendency of a drum to "bell" slightly at the ends. Even so, the above drum ends measured $48^3/_{32}$ in. inside at the seam and $47^{15}/_{16}$ in. at right angles to these measurements, while in the middle the out-of-roundness was negligible.

Ten-foot diameter cylinders of fairly heavy plate thicknesses have been welded in the same manner with remarkably good results.

Deciding on how much a vessel should be "jacked up" isn't nearly as complicated as it seems and soon becomes routine. Also the drums having wall thickness $1^3/_4$ in. and under can be welded all the way to top of groove, the supports removed and inside welding done, with just as good results.

The greatest satisfaction and saving of labor was obtained when a group of sixteen "thick and thin" drums, approximately 48 in. inside diameter with $2^9/_{16}$ in. tube plates and $1^3/_{16}$ in. wrapper plates (Fig. 4) were welded by the above method. These drums were almost perfect after welding, several being only $^1/_{16}$ in. out-of-round and the maximum being $^5/_{32}$ in. out-of-round. One can easily imagine how difficult these seams would be to re-form if they were distorted beyond the tolerance. Figure 5 shows one of the drums with supports in place ready for welding.

The Foster Wheeler Corporation has also fabricated in the above manner with excellent results, 42 in. I. D. drums, 2 in. thick, 25 ft. long, having two longitudinal seams. The radius of drums at the seams was more uniform than one could hope to obtain by re-forming cold, and the cost of labor in obtaining these results was low in comparison with hot rolling such cylinders.

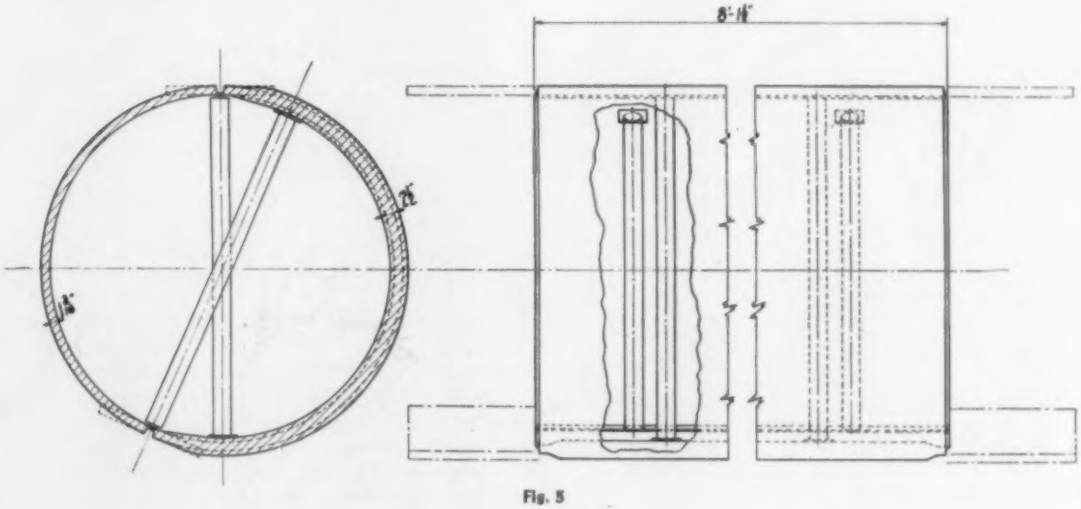


Fig. 5

Fabricating Tool Equipment and Machine Parts by the Torch Cut and Weld Method*

By P. H. DANLY†

ANY man who is engaged in the interesting work of designing and building tool equipment is aware of the fact that he and his art, to a large degree, lead the way in this age of machine specialization.

The product of the tool engineer's creative ability in the form of tools, dies, jigs and fixtures is equally as specialized as the art itself.

Tool equipment of this kind is almost always special purpose, usually produced in single units, or at most, low multiples.

With this background of technique and product it is only natural that the cutting torch rapidly assumed an important place in the picture.

Of course, we all know that it owes a great deal of its importance to the fact that its use is a preliminary step in utilizing its closely related companion tool—the electric arc welder.

However, the cutting torch can stand strictly on its own feet in pointing to five very important contributions it has made to modern fabricating procedure.

(1) It freed the designer from many limitations due to the material used and in some cases made possible types of construction that could never have been considered from a foundry standpoint.

(2) Eliminated pattern costs, often as much on single run job as the cost of the part itself.

(3) Reduced weight, always an important item in operating costs of parts moving under power.

(4) Made freer experimentation possible and made easier alterations in the equipment at any phase of the building at lower cost.

Fig. 1—Automatic Gas Cutting Four Pieces at a Time

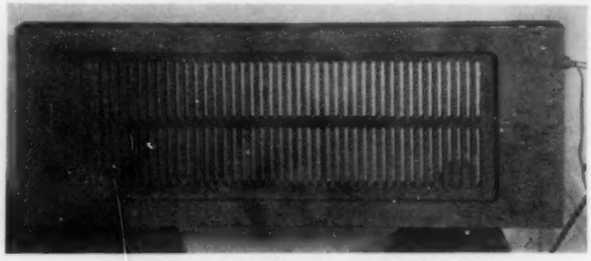


Fig. 2—Cutting Die Holders with Many Slug Relief Slots

(5) Produced greater rigidity, a prime requirement in any type of tooling, with less weight.

The first four of these five features are very commonly recognized and need no explanation. The fifth, however, is worthy of some elaboration.

Resistance to Deflection Governs Rigidity of Tooling

The important factor in the design of machine tools and their necessary tooling equipment is not their ultimate strength but their resistance to deflection under a given load. Naturally, the use of a material providing greater resistance to deflection will tend to increase the rigidity of the tooling—improve the quality of the work—and aid in establishing higher production and lower costs.

Rigidity is the prime requirement of machine tool equipment. Their structure's deflection, or we might say the amount of deflection allowable, is directly controlled by the modulus of elasticity of the material from which it is made.

The modulus of elasticity of steel is approximately $2^1/_2$ times that of cast iron. This fact makes it possible to greatly reduce the weight of the structure and still achieve the same rigidity, or deflection when under load.

While this fact applies to both steel castings and to steel plate, in actual practice torch cut rolled steel offers superiorities for tooling equipment. Steel is more homogeneous than cast iron—its easily determined physical properties are practically constant. It can be bent or formed to virtually any desired shape without important changes in its physical properties.

In comparison with cast steel, the physical qualities are little different, but rolled steel is much more uniform and reliable. There is not the same danger of blowholes, segregation, undesirable grain structures and internal strains from shrinkage. Steel plate construction—torch cut and welded—does not hamper the designer with the old restrictions. It presents no problems pertaining to patterns, shrinkage or flow of metal in the molds.

While its physical superiorities are self-evident—it derives its most important advantage from the fact that

* Paper to be presented at Fall Meeting, AMERICAN WELDING SOCIETY, week of September 30, 1935, in Chicago. Copyright 1935 by P. H. Danly.

† Danly Machine Specialties Company.

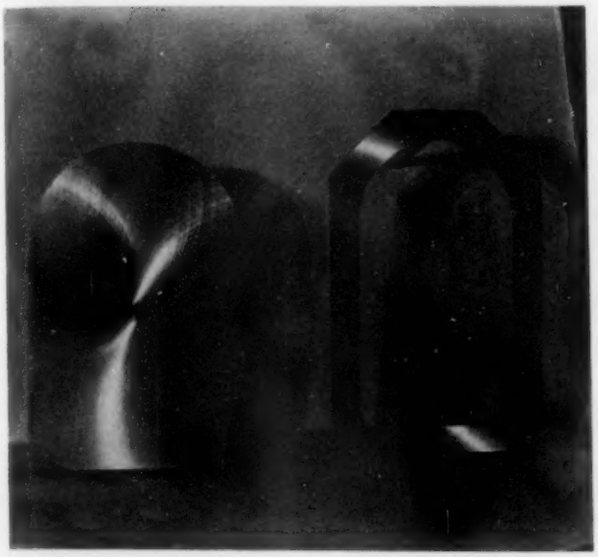


Fig. 3—Machine Cutting Stripper Plates and Pressure Pads Used on Blanking and Forming Dies

special tooling equipment is always a "one time job." It can usually be torch cut and welded in less time—and for less money—than would otherwise be spent to produce the necessarily intricate pattern.

These facts and the modulus of elasticity figure are true of all types of rolled steel of qualities from tank plate up to the alloys. The final selection of the steel will depend upon the following factors: (*a*) Welding qualities; (*b*) resistance to wear on jobs where this quality is essential; (*c*) stresses in structures of machine design sometimes require steel of higher tensile strength, elastic limit or compressive strength. In such cases, higher carbon or alloy steels may be used to advantage.

Designing Tool Equipment from Rolled Steel

Having briefly summarized the advantages of rolled steel as a material for tool equipment, let us consider the problems in designing for its use—and its method of fabrication with the highly specialized knowledge and skilled technique necessary to the successful use of that method.

When designing from rolled steel—cautiousness, due to the influence of previous experience with cast metals, is more apt to restrict the possibilities of tooling built from this material than any limitations of the material itself.

The real improvements and economies of rolled steel construction do not become fully apparent unless the designer starts from "scratch" with a careful analysis of the functions of the tooling under consideration. While starting from "scratch" to design in a new and unfamiliar material presents obviously serious difficulties, the experiences of the last few years have made it increasingly clear that "cashing in" on all the possible benefits of rolled steel construction is an impossibility unless this "starting from scratch" procedure is followed.

Machine Torch Cutting of Rolled Steel for Tool Equipment

We are all familiar with the oxygen cutting torch and the rapid increase of its use since its invention.

The torch, replacing some other form of machine cutting tool, travels along over plates of steel ranging from very thin sections up to thicknesses far beyond the possibilities of other cutting agents, simultaneously cutting a narrow slot or kerf through the plate. Its direction of travel is governed by the shape of the pattern or drawing on the machine. Almost any conceivable shape can be quickly cut from steel plate by this device and set-up.

In the hands of a skilled mechanic the torch cuts shapes from steel plate to such accuracy that in many cases they can be used without further machining.

Substantial economies can be effected in the manufacture of tools because of this fact.

For instance, in building tools for the metal stamping industry, die holders are sometimes required with so many slug relief slots that the thinness of section and the amount of coring involved make it impractical to cast them. In the past it has been necessary to machine these slots from a solid casting—a rather long and very costly operation.

Due to a carefully acquired experience in the applications of torch cutting these slots can now be cut by this method—shop time is reduced and a great saving in costs results.

An interesting example of this particular operation was a job having 82 of these slug relief slots $^{7}/_{16}$ in. wide x 6 in. long on $1^{1}/_{8}$ in. centers—cut from 2 in. plate (see Fig. 2). Skilful use of the torch made it possible to cut these slots rapidly and effect an amazing reduction in costs.

Additional emphasis on the speed of the cutting is appropriate here in view of the fact that the width of the slots is $^{7}/_{16}$ in.—and they were cut accurately without the faintest trace of notching.

Of course, the ability to use the torch with such accuracy and to such advantage did not come overnight. It required some intensive study and some dearly bought experience, but the fact remains that the savings—when made—were very real.

Another example of the savings resulting from machine torch cutting of tool equipment is furnished by the stripper plates and pressure pads used on blanking and

Fig. 4—Machine Torch Cutting in More Than One Plane

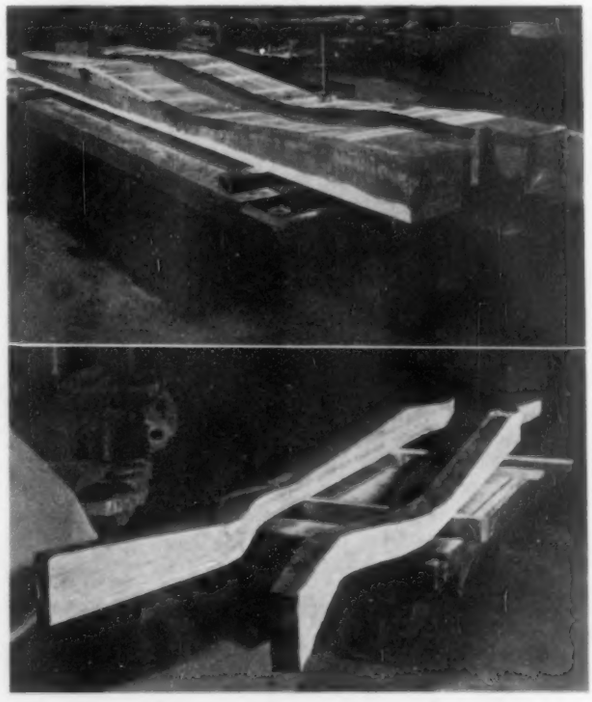


Fig. 5—Side Rails of Dies Machine Cut

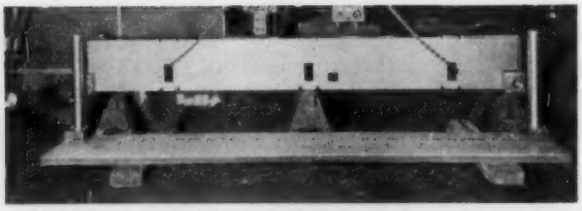


Fig. 6—Die Set for Automotive Frames, Weight 10,900 Lb., Made of Steel Plate with Steel Bosses Screwed and Doweled in Place. Note Relief for Bolt Heads in Bolt Slots and Cut Outs in Shoe and Holder

forming dies (see Fig. 3). Formerly the manufacture of these parts required a lot of time for layout, drilling, sawing and filing to shape them to fit over the punch or in the die.

They can now be torch cut with such accuracy that they are used without further machining except for a small amount of planing or grinding on the flat surfaces; and even this operation can often be eliminated by the use of cold rolled steel.

An illustration of the fact that machine torch cutting is not confined to cutting in one plane only is furnished by the cutting of these pressure pads for automobile frame dies (see Fig. 4).

In the plan view these parts are cut to the shape required by the double drop frame. They are then turned at 90°. The top face is then cut to the shape required by the frame at the point where it narrows down for the motor mounting, etc. This leaves the bottom face a straight line for bottoming on the die holder.

The side rails of these dies are cut in a similar manner (see Fig. 5)—in some cases through thicknesses up to 22 in. Extreme care and proper pressure control made it possible to make these heavy cuts without slowing up—at no time was there any delay due to "starving of the tip."

These parts were completely machined over-all on a Keller die sinker and the time saved by not having to work through the sand and scale encountered on the surfaces of steel castings effected a great saving in cost on this job, in spite of the fact that in this particular case, the torch cut metal and the material required were equal in cost with steel castings.

Another typical example of the advantages offered by this method of fabrication is furnished by this die set for automotive frames (see Fig. 6). It is 24 in. wide and 192 in. long, and weighs 10,900 pounds. Shoe thickness is 3 in. and holder $5^1/_2$ in. The relief for bolts lots and the cut outs in shoe and holder were torch cut so accurately that there was no need for further machining at these points.

An illustration of the unusual designs made possible by the rolled steel construction is furnished by this 4000-pound die set (see Figs. 7 and 8).

Its construction illustrates a point mentioned previously—the full benefits of the use of machine torch cutting do not become fully apparent unless it is used as a part of the electric arc welding method of fabrication.

Fig. 7—Die Set Made from Rolled Steel Construction

Building Better Machine Parts Faster—at Lower Cost—by the Torch Cut and Weld Method

A discussion of machine torch cutting of tooling equipment naturally leads into the industry's sister art—the Torch Cut and Weld Fabrication of Machine Parts.

The advantages of this method are just as plainly apparent in building special machine parts as in building special tooling equipment—in fact, the theory of design and construction is practically identical.

Much of the same theory that applies to the design of tooling equipment from rolled steel also applies to machine parts built from this material. Again, the designer must start from "scratch," with a careful analysis of the machine and its component parts. However, one very decided advantage in new design is offered by rolled steel: it makes possible certain devices such as the box section which make it easier to actually compute complicated stresses and to achieve the great rigidity so essential in machine construction—at the same time reducing weight.

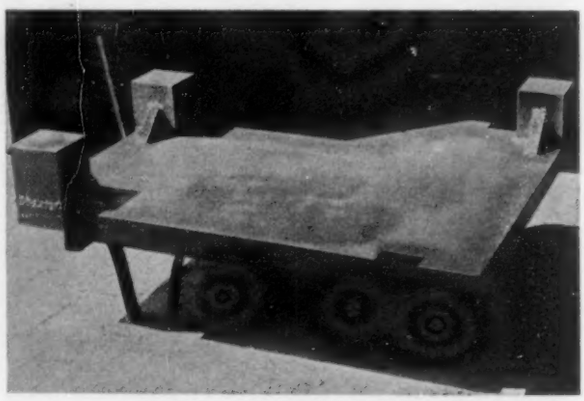


Fig. 8—Die Set Made from Rolled Steel Construction

In the construction of high production machinery—complicated as it is in design, construction and operation—it can be positively stated that under such conditions, the machine can invariably be constructed at lower cost by the torch cut and weld method.

Another important advantage that this method brings to the building of special machinery is the great saving of time and money that it makes possible whenever it is found necessary to make changes and alterations in design and structure during the process of construction. Rolled steel and torch cut and welding, therefore, make it easier to cut the cost of experimentation in new principles of design and construction. Figure 9 is the front end bed section of a large planer type milling machine measuring 3 ft. x 11 ft. x 43 ft. This machine part weighing 55,664 lb. illustrates the possibilities of torch cut and weld fabrication.

Rolled Steel Machinery Gives New Eye Appeal

Experience is teaching us that rolled steel machinery's pleasing appearance makes it more salable. It has a very different and definite spirit of rugged beauty. In torch cut and weld fabrication of rolled steel machinery, it is possible to obtain a very pleasing proportion of masses. The smooth, flat surfaces of this machinery portray strength and simplicity. These facts are dramatized by this clearing 4-point all steel press built by the torch cut and weld method (see Fig. 10). Note the pleasingly smooth and workmanlike appearance of the surfaces of the uprights; an effect that is very evident here in spite of the fact that this picture was taken when only the priming coat of paint had been applied.

The Use of Steel Castings in Torch Cut and Weld Fabrication of Rolled Steel

While naturally enthusiastic about the advantages of rolled steel construction by the torch cut and weld method the speaker is well aware of the fact that there can be no entirely satisfactory substitute for steel castings in certain applications in machinery building.

I consider it highly advisable to incorporate castings into rolled steel construction on certain jobs and for certain purposes; and I believe that one of the greatest benefits of the electric arc welding method of fabrication is the fact that it enables us to build steel castings into this new type of construction and thereby secure the benefits offered by both materials.

An interesting example of this point is this press Sub-Bed showing cast steel gear boxes for the adjusting screws welded with the main frame construction of steel plate (see Fig. 11).

The Designer in Torch Cut and Weld Fabrication

Much progress has been made in machine tool construction during the past few years, and the industry deserves great credit for continuing its progress and development during the depression years and their almost complete stagnation. Credit is due to those men who have gone ahead unhampered by inhibitions resulting from previous experience and who are unafraid to ignore restrictive traditions. These facts are convincingly dramatized by the progress made in torch cutting and electric arc welding and its application in the machine tool industry during the past few years.

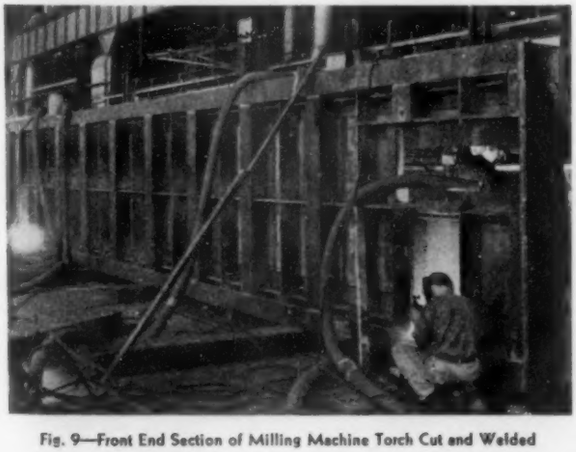


Fig. 9—Front End Section of Milling Machine Torch Cut and Welded

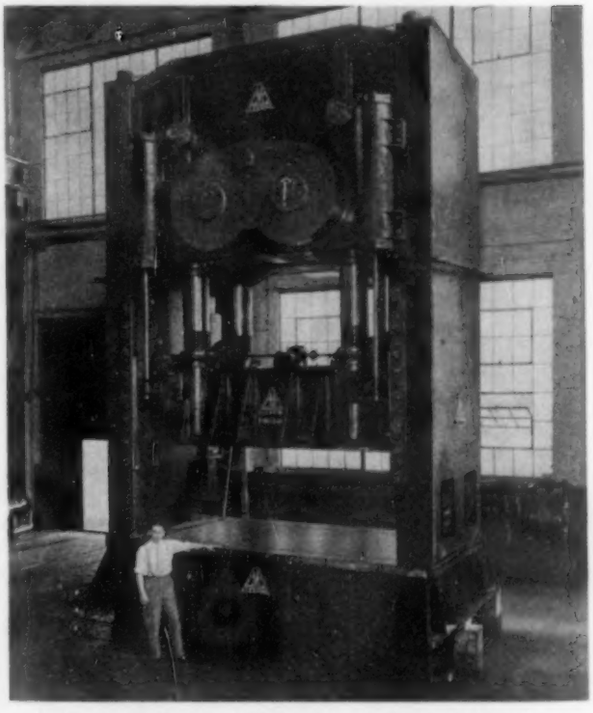


Fig. 10—All Steel Press Built by the Torch Cut and Weld Method

Experience and Skill Essential to Success in Torch Cutting and Welding

In conclusion, it is necessary to point out that building machine parts, or tooling equipment, by the torch cut and weld method of fabrication—while presenting many and obvious opportunities for savings—also presents some difficulties, and they, unfortunately, are not so obvious

Experience and *skill* are under-rated factors in practically every line of endeavor and the welding business is no exception.

Their sum total as applied to this field can be briefly defined, however.

It consists of having the knowledge necessary to decide which job, or which part of which job, is suited to rolled steel construction—the ability to start the design from "scratch"—and the skill and facilities to put the job into production and carry it through with no doubts as to its successful outcome.

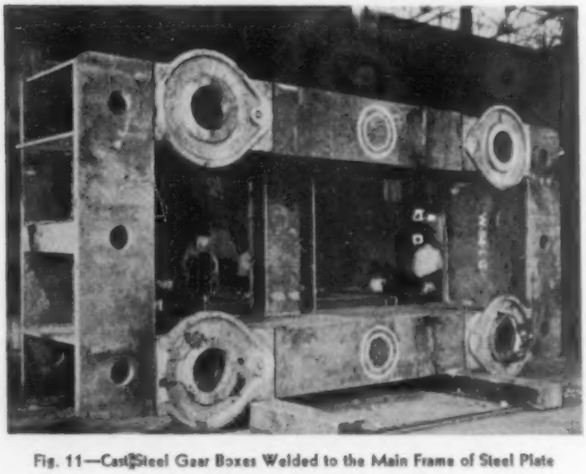


Fig. 11—Cast Steel Gear Boxes Welded to the Main Frame of Steel Plate

A New General-Purpose Meter for Resistance Welding*

By C. STANSBURY†

ANYONE having contact with a number of different resistance welding installations is likely to be impressed by the scarcity of suitable measuring devices. Whatever may be the extent to which manufacturers of spot welders use scientific quantitative methods, it must be admitted that among the users of such apparatus there is little tendency to attack resistance welding problems on the basis of measurement of the various physical quantities involved. In fact, resistance welding is in many plants very much in the stage of a rule-of-thumb art, something like that of the old-fashioned blacksmith.

The purpose of the present article is to describe a new meter which the writer believes has sufficient utility in this field to improve this situation considerably. Before taking up this specific device, however, it may be well to consider a few of the physical quantities involved in even the simplest resistance welding operation, and to discuss briefly the situation as regards practical shop measurement of each.

1. *Electrode Pressure.*—Devices are available for measuring this quantity, but are not in common use. Doubtless one thing that complicates the situation is that in many modern spot welders the electrodes are not merely pressed together, but are brought together with a hammer blow so that a measurement of the static pressure between electrodes would doubtless tell only part of the story.

2. *Secondary Current.*—By this is meant the current passing between electrodes during the weld, as distinguised from the current to the primary of the welding transformer. It is practically never measured, because of the difficulties inherent in measuring an alternating current of very large magnitude which flows for only a fraction of a second. It is, however, readily measured with the type of meter described in the present article.

3. *Primary Current.*—There are a number of obvious reasons why measurement of this quantity is desirable:

1. To provide a fair basis for judging the performance of the switching apparatus in terms of actual currents handled rather than estimated (estimated welding primary currents are generally about half the actual values).

2. To guide in purchase of switching apparatus for similar work.

3. To give definite information regarding the momentary loads on the shop supply lines.

Measuring the primary current is easier than measuring the secondary current, but is by no means without difficulties. In present-day practice the welding periods are commonly as short as three or four cycles and at times as short as one cycle. The ordinary ammeter is useless for periods shorter than possibly one-half second, although it is surprising how often one encounters electricians naively watching the wild swing of the needle of an ammeter on a five cycle welding period and solemnly reporting that the current is some definite value. An ammeter with an adjustable back-stop behind its needle is good for such measurements, the back-stop being moved up on successive welds until a point is reached at which the needle will barely move. The movement of the needle is somewhat erratic, due to variable inrush transients, but with a little practice accurate results are obtainable. However, one seldom finds this method in use, although the scheme has been used for many years in measuring motor inrushes.

The only alternative heretofore possible, as far as the writer knows, is the oscillograph which, of course, is out

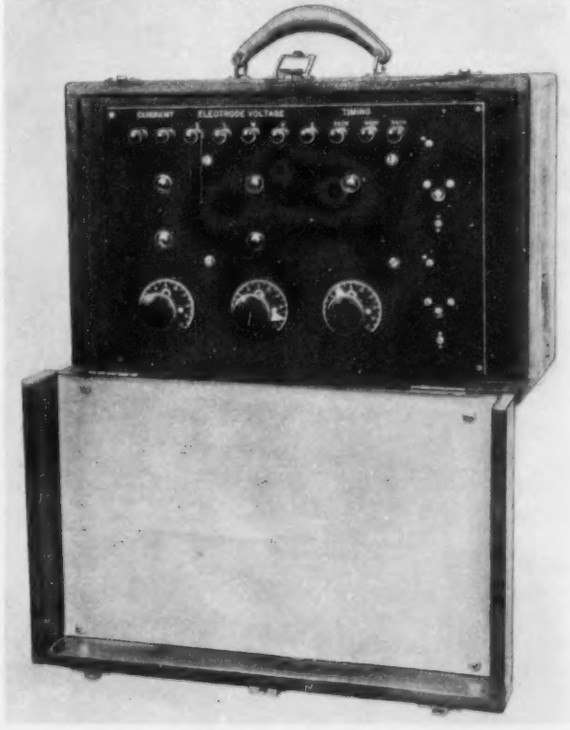


Fig. 1—General-Purpose Resistance Welding Meter—Glow Tube Type

* Paper to be presented at Fall Meeting, American Welding Society, week of September 30, 1935, in Chicago.

† Research Engineer, Cutler-Hammer, Inc.

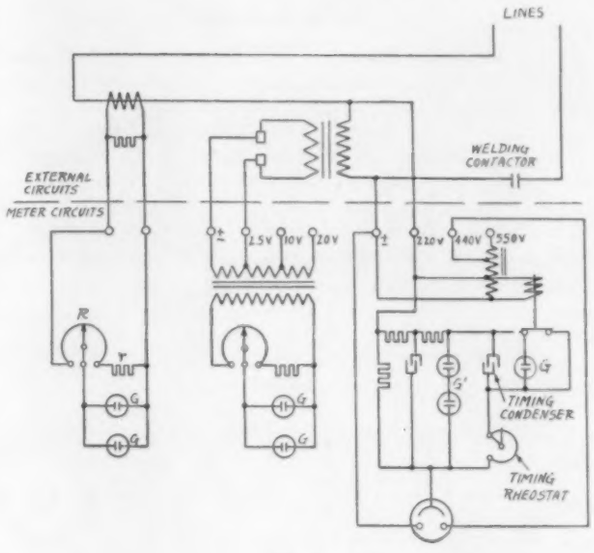


Fig. 2

of the question for routine measurements, even if available.

4. *Welding Voltage* (between electrodes).—Measuring this quantity presents the same difficulties as the determination of the primary current. Here again on short time work we have had only the back-stop meter or the oscillograph.

5. *Time of Current Application.*—Instruments suitable for measuring the welding period with satisfactory accuracy are available, but they are rather expensive and are not commonly used, even by large users of welding apparatus.

6. *Current and Heat Distribution.*—These two important variables remain very much in the realm of guess-work and rule-of-thumb, primarily because we seem to have no instrument-eyes to see what is going on.

The Glow Tube Welding Meter

It will be clear from the above list of variables that a general purpose meter for resistance welding should be capable of measuring both the primary and secondary welding current, the welding voltage and the duration of the weld. These are the measurements provided for in the design of the glow tube welding meter shown in Fig. 1.

There are three dials corresponding to measurement of current, electrode voltage and time. Above the current dial are located two small Neon glow tubes, above which are the two current terminals which are provided for connection to the secondary terminals of a current transformer suitable for the range of current to be measured.

Above the middle dial there are also a pair of glow tubes above which are four terminals for connection to the welding electrodes, providing for voltage ranges having maximum values of 2.5, 10 and 20 volts. Finally above the right-hand dial there is a single glow tube above which are located terminals suitable for different line voltages and intended to be connected across the primary terminals of the welding transformer in order to measure the duration of welds.

The circuit of the device is shown in Fig. 2, this diagram being so drawn as to correspond to the actual arrangement of parts in the meter of Fig. 1; namely, with the current measuring dial on the left, electrode voltage dial, center, and time dial, right. The operation is based on two facts: first, that an ordinary cold-electrode Neon glow tube has a definite critical voltage which has to be exceeded before a glow discharge will start, and, second, that a glow discharge for as short a period as one cycle can readily be seen.

Referring to the current-measuring portion of the circuit, which includes the voltage-divider rheostat R and its series resistor r, assume that a current is flowing in the primary of the welding transformer. Then there will be a voltage across R and r which is proportional to the value of the primary welding current. Provided this voltage is higher than the critical voltage of the glow tube, it will be possible, by adjusting the position of the brush of rheostat R, to find a position on one side of which a glow in one of the tubes is obtained, while on the other side of this position the tube does not glow. Furthermore, for a given current transformer it is possible to calibrate the dial of R on this basis and in terms of primary current flowing through the current transformer. Two glow tubes are used because, as there is always a slight difference in the critical voltage of these tubes, the use of two facilitates making a reading as it permits so setting the dial that one tube glows and the other does not. This has been found in practice to be a great convenience in making readings.

The principle of the circuit for measuring electrode voltage is the same, the only difference being the inclusion of a step-up transformer to obtain voltages suitable for operating the glow tubes.

The circuit for measuring time is somewhat similar in principle to the above. The A.C. voltage from across the primary of the welding transformer is rectified and smoothed out and used to charge a condenser through a calibrated rheostat. This rheostat is so adjusted during successive welding operations that the voltage across the condenser just barely reaches the critical value which will cause a glow in the glow tube at the instant that the weld is terminated. A magnetic relay is provided to short circuit the condenser between welds to dissipate its charge. The function of the additional glow tubes G' is to stabilize the output voltage of the rectifier and make the time reading relatively independent of fluctuations in the supply voltage.

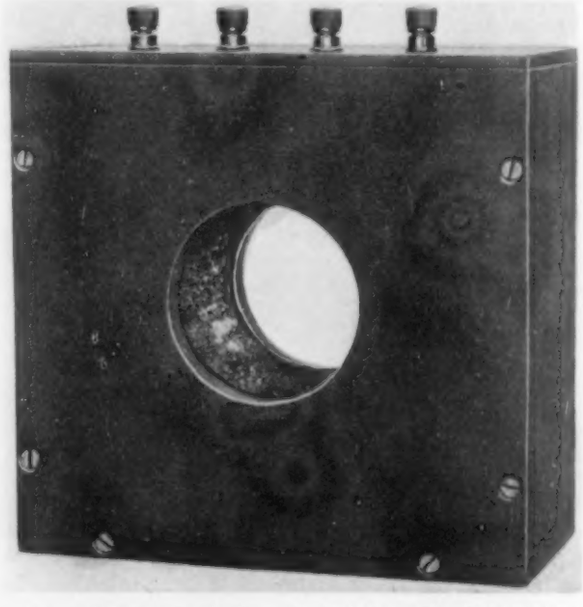


Fig. 3—Air-Core Current Transformer for Use with Glow Tube Welding Meter

Current Transformer

The development of a current transformer for use with this meter, for connecting in the primary circuit of the welding transformer, presents no particular difficulties because the only thing wherein it differs from an ordinary instrument transformer is in the use of relatively low secondary current with secondary voltages on the order of 50 to 250 volts, over the range of use of the meter. Moreover, the accuracy requirements are nowhere near as severe as in ordinary current transformer work.

However, a current transformer for measuring the secondary or actual welding current proved to be a difficult problem because of the magnitude of the currents involved. For instance, the minimum secondary current on a certain small machine (10 kva.) was found to be 5300 amperes and secondary currents of 10,000 to 20,000 amperes and higher are common. As a fundamental requirement in an ordinary iron-core current transformer is that the secondary ampere turns must be substantially equal and opposite to the primary ampere turns, an iron core current transformer for currents of such magnitude becomes an unreasonably bulky, heavy and expensive device. As a substitute, therefore, an air-core current transformer was developed (Fig. 3) which avoids these difficulties and at the same time has the same features as an ordinary window type iron-core current transformer in that the reading is independent of the position of the conductor within the window and that it is possible to multiply the range of the current transformer by using several successive passes of the conductor through the window. The arrangement of parts in this current transformer is shown schematically in Fig. 4. It consists of a wooden toroid on which are mounted at 60° intervals small coils of fine wire. The coils are connected in series and the end connections brought out to a pair of terminals as indicated. In the actual transformer there are a total of eighteen coils symmetrically arranged and providing for the use of 6, 12 or 18 coils depending on the range of current to be measured. It is this symmetrical location of the coils which gives a compensating action so that the secondary voltage is substantially independent of the position of the primary conductor within the window of the transformer and also permits use with repeated passes of the primary conductor as indicated above. With the particular current transformer shown in Fig. 3, used with the glow meter it is possible to measure currents up to 40,300 Amps. and the measurement of higher currents is a simple matter of design.

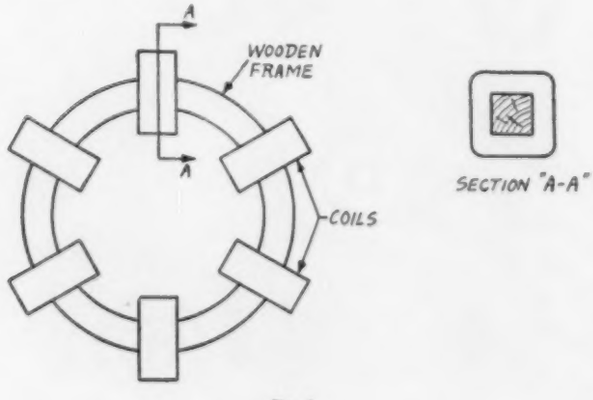


Fig. 4

Calibration Data

In order that a meter of this type may have maximum usefulness, it was essential to put the calibration data in such form as not only to give the quantitative information needed, but also to serve as a guide in the use of the instrument. With this in mind, curves were rejected as a form for the data and the information was put up in tabular form. A part of the calibration sheet is shown in Table 1, which incidentally illustrates how the air-core current transformer is used for making readings ranging from 680 to 40,300 Amps.

Table 1

Dial Setting	Ampere Readings with Air-Core C.T. Using Secondary Term Indicated			Ampere Readings with Air-Coil C.T. Using Terms 1–4 and Number of Passes through Window Indicated		
	1–2	1–3	1–4	2 Passes	3 Passes	4 Passes
0–3	7070	3840	2720	1360	905	680
5	7180	3900	2760	1380	925	690
10	7480	4060	2880	1440	960	720
15	7820	4250	3000	1500	1000	750
20	8180	4490	3140	1570	1050	785
25	8570	4650	3300	1650	1100	825
30	9010	4890	3460	1730	1150	865
35	9500	5190	3670	1835	1220	915
40	10100	5480	3880	1940	1290	970
45	10700	5820	4110	2160	1370	1030
50	11500	6240	4420	2210	1470	1100
55	12300	6680	4730	2360	1580	1180
60	13300	7250	5136	2570	1710	1280
65	14600	7920	5610	2810	1870	1400
70	16000	8720	6180	3080	2060	1540
75	17900	9720	6880	3440	2290	1720
80	20200	11000	7770	3880	2580	1940
85	23100	12600	8920	4460	2970	2230
90	26700	15100	10700	5350	3560	2670
95	32100	17500	12300	6150	4100	3070
100	40300	22000	15500	7750	5160	3870

Factors Affecting Accuracy of the Glow Tube Meter

There are several factors which affect the accuracy of a meter of this sort and it must be admitted that the accuracy is low as compared with that, say, of a good D.C. ammeter. In the first place, the accuracy depends on the quantity being measured, such as the welding current, remaining constant during the welding period. As is pointed out below, in the usual case the welding current and welding voltage changes only very slightly.

Another factor which obviously affects the accuracy of this meter is the wave shape of the current or voltage. As the meter is calibrated on the basis of sine waves, its accuracy is affected if the wave shape differs materially from the sine wave. The writer has, however, not encountered any instances where this is the case.

A final factor in the accuracy has to do with the variation of critical voltage of the glow tubes in service. A number of new commercial glow tubes have been found to vary from the average by about ±4% but the writer does not have any data on the variation throughout life. It should be pointed out however that the total time in which a glow tube in a meter of this sort is actually glowing is very small. In other words, even if the meter is to be used rather frequently, it is not left connected for any length of time and a few hundred hours' service of the glow tubes will probably correspond to several years of normal use of the meter.

The writer believes that with reasonable care in construction with calibration and selection of glow tubes, an accuracy of ±5% should be readily obtainable with a meter of this sort, which should be adequate for the purposes involved.

Resistance Welding on a Quantitative Basis

We have seen above that this new meter measures primary and secondary currents, electrode voltages and the duration of welds. As has been pointed out, the primary current is of interest principally in connection with switching apparatus and a knowledge of the load being put on the shop line.

However, the secondary current, electrode voltage and time are directly related to the energy input to the weld and so are of fundamental interest in connection with the study of different welding methods and the capacity and efficiency of different machines. For the sake of brevity in the discussion that follows, let us give these three quantities the symbols:

E = Voltage between electrode tips during welding (r.m.s.)
I = Current passing between electrodes through the material during welding, that is, secondary current (r.m.s.)
T = Duration of weld in seconds
W = Total energy dissipated between electrodes during the welding period

If we assume that E and I are approximately constant throughout the weld and that I is approximately in phase with E, we can express the total energy input of a given weld as $W = EIT$.

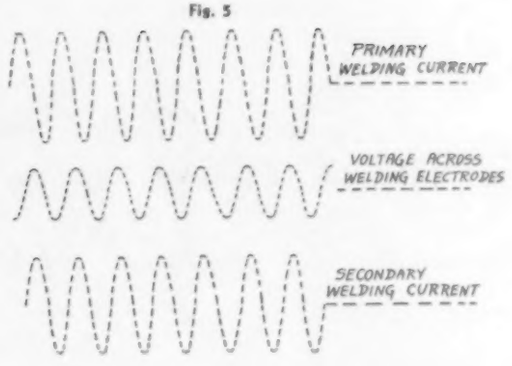
A number of oscillograph tests of spot welds were made to determine whether the assumptions mentioned above correspond at least approximately to actual conditions. From these oscillograms, Figs. 5 and 6 are shown here as illustrating typical conditions. In the case of Fig. 5, the welding electrodes were pressed together directly without intervening material and the figure clearly shows a uniform sine-wave voltage across the junction between the two electrodes, and a uniform secondary current which is for all practical purposes in phase therewith. For Fig. 6 conditions were the same except that two pieces of steel were interposed and an actual weld made. It will be seen that there is a falling off in electrode voltage and some rise in welding current, but that both these changes are relatively slight. The curves show E and I to be practically in phase.

In speaking here of unity power factor relation between E and I, it is to be emphasized that this relates strictly to the relation between electrode voltage and electrode current and not to the question of the power factor of the input to the welding transformer or even the power factor of the secondary circuit where the secondary voltage is measured anywhere except right at the welding electrodes.

Conclusion

It should be pointed out that the actual energy that is useful in welding is less than W, as W includes all the energy dissipated between electrodes, some of which is commonly lost in stray current paths and in heating parts of the metal remote from the surfaces to be welded.

Fig. 5



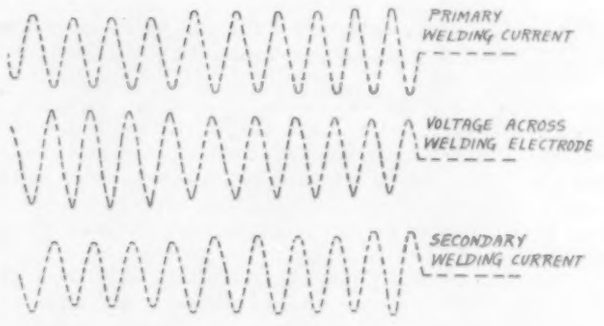


Fig. 6

Nevertheless, the above equation represents as close an approach to the actual energy input into the weld as we are likely to obtain by measurement, and does represent the energy output of the spot-welder with an accuracy sufficient for the purposes involved.

These purposes are fundamentally the identification of different welding jobs as requiring certain known amounts of input energy, with appropriate corrections taking into account the fact that more input energy is required where the weld is made with longer time and smaller currents, because of greater heat losses. Such knowledge would enable the user of welding equipment to specify definitely to the welding machine manufacturer the rate of energy input to the actual weld instead of buying welding equipment on the present basis which appears to be based primarily on the kva. taken by the welding transformer from the line. It has often appeared to the writer as if the present rating system with relation to resistance welders is analogous to the situation we would have if motors were sold on the basis of the kilowatts they draw from the line rather than on the basis of the horsepower they deliver at the shaft.

Apart, however, from its uses in purchasing and judging welding apparatus, a meter of this sort should have value in the different variables on the quality of work produced, the correct allocation of different welding jobs among the various machines available, and so on.

Some Effects of Generator Characteristics on Welding Costs*

By JOHN H. BLANKENBUEHLER†

GENERATOR designers have for years been improving the welding performance of welding generators and have been labeling their machines as "surgeless," "droopless," "fast," "smooth," "flexible," etc. Purchasers have been subjected to wonderful expositions on the subjects of current transients, stability factors, mutual inductances, etc. Rarely, however, has any one shown the purchaser those less abstract data involving the cost of welding in which he is far more vitally interested.

Some data on this point are available and this paper will present first, some features of generator performance which affect the welding operation, and second, the results of tests conducted to evaluate these effects.

In a paper presented before the American Institute of Electrical Engineers in 1931, the writer expressed some theories on how a welding generator should perform to make welding easy and also how this improvement of performance affected the metal transfer during welding. The fundamental idea of this paper was that the generator should be so designed as to minimize current changes during welding.

This deviation of the welding current from the average value shown on the meter may be caused in several ways.

Each type of welding generator has a definite relation between the voltage at its terminals and the welding current for a given current setting. This relationship is known as a voltampere curve and is usually plotted as shown in Fig. 1. This shows the current voltage relationship for six different current settings through the range of this particular set. Now if we assume our set is adjusted to one of these curves as shown in Fig. 2 and our ammeter shows a welding current of 175 amperes, at an arc voltage of 20 volts we can see that if the arc is shortened to 15 volts the current rises to 185 amperes. At short circuit the current rises to 210 amperes.

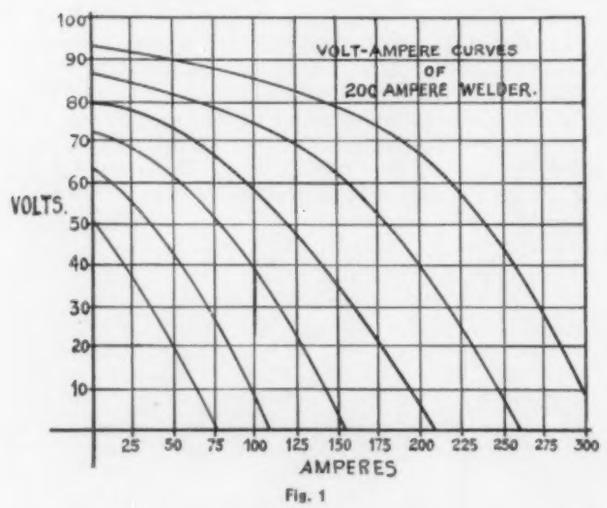


Fig. 1

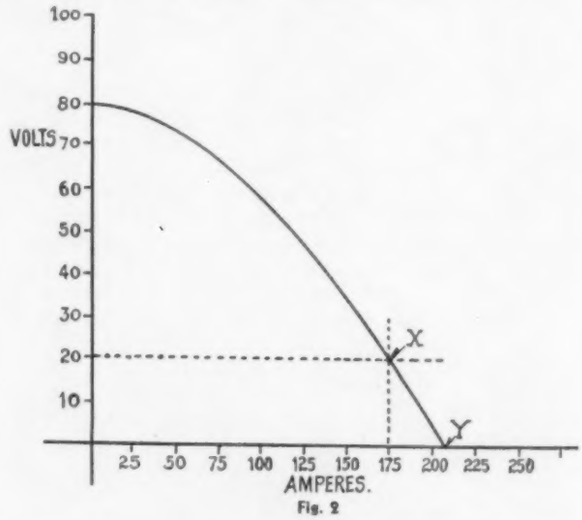


Fig. 2

However, as was brought out in the paper mentioned above, the welding current supplied by a generator rarely coincides with the current indicated by the voltampere curve of the generator. This is generally due to harmful inductances in the generator which act as an electrical inertia to prevent the generator from changing its voltage and current output as rapidly as the changing conditions in the arc require. Thus, instead of changing as shown in Fig. 2 the arc current will change as shown in Fig. 3. Thus as the voltage increases from zero to 25 volts instead of the current changing from 210 to 165 amperes, it may actually droop below 165 amperes during the change and will often go as low as 140 amperes. Similarly when the voltage decreases from 25 to zero the current may overshoot or surge to a maximum value of 300 amperes instead of just increasing to 210 amperes as would be indicated by the voltampere curve.

The voltampere curves in Figs. 1 and 2 are called the static characteristics and the deviations therefrom shown in Fig. 3, the dynamic or transient characteristics.

If the arc current droops too low as the arc is lengthened, either due to the static or dynamic characteristics of the generator, the arc will go out. This results in a crater which must be carefully worked over to prevent

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* Paper to be presented at Fall Meeting, AMERICAN WELDING SOCIETY, week of September 30, 1935, in Chicago.

† Westinghouse Electric & Manufacturing Company.

its being a bad place in the weld and the least harm this excessive current droop can do is to slow up the work.

The welding arc is short circuited many times per second by the molten globule of steel which forms on the end of the electrode and which, as it gets larger, finally touches the work. Excessive increase in the welding current due to this short circuit will vaporize some of the metal in the molten globule, thus blowing part of the globule away from the seam and leaving some gas pockets in the remainder. This short circuiting of the arc by the molten globule occurs much less with coated electrodes, which have longer arcs, than with bare electrodes, and is possibly one of the reasons we get better welds with the coated electrodes.

Therefore, assuming that it is desirable to keep the current constant during welding, we can see that we should have a generator with a steep voltampere curve, i.e., one with a minimum change of current for any change of voltage and also one with excellent transient characteristics, i.e., one which forces the current and voltage to follow closely the static characteristics during changes in the arc.

Whereas the above is one theory there is another school of thought which argues for constant power in the arc. There always has been, and probably always will

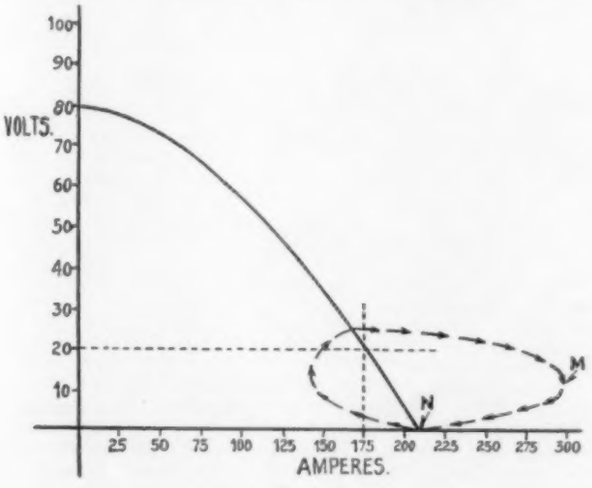

Fig. 3

be, controversy between the proponents of voltampere curves indicating a constant current in the arc and those indicating a constant power in the arc. There is, at first glance, logic in the idea that we should have constant power in the arc regardless of changing arc length. Less than one-half of the heat of the arc is used in melting steel, however, the rest being wasted in warming up the plate and air, etc.

Increasing the arc length will therefore increase the power required by the arc because the length of the arc stream radiating heat to the air is increased. Even more important is the fact that a voltampere curve giving approximately constant power with changing arc voltage gives a very great change of current for a change in voltage and a short circuit current that is tremendously greater than the welding current. This extra large short circuit current makes the electrode stick when starting the arc and increases the spatter and porosity.

In an effort to learn whether the theory, which indicated that the generator should maintain the arc current constant during welding, was correct, a number of tests were run.

First several generators were tested to determine their voltampere curves or static characteristics as shown in Fig. 1, and their transient current surge or overshoot when short circuited. Using these data an empirical figure based on each generator's ability to hold the current constant was set up. This figure was made up of two factors "A" and "B." Factor "A" was the ratio of the short circuit current (y on Fig. 2) to the welding current (x on Fig. 2). Factor "B" was the ratio of the maximum current surge on short circuit (M on Fig. 3) to the final steady short circuit current (N on Fig. 3). Multiplying these two factors "A" and "B" together gave an empirical factor "C" which indicates the current constancy. The less this factor "C," the more constant the current and the better the generator should weld.

Up to this point theories on how the shape of the voltampere curves and the dynamic characteristics may affect welding have been presented. Quite logically the next question is how to prove these theories by actual tests with generators of different characteristics.

Tests to corroborate this theory are extremely complicated and require exceptional attention to detail. The general plan is to have an operator weld with the different generators at exactly the same current and arc voltage and with the same electrodes This is impossible. Minor differences of current and voltage will always occur and will introduce other variables which are difficult to evaluate and make it necessary to discard and repeat many tests. Even though all tests are run from one box of electrodes the differences between individual rods are considerable. The only reasonable way to eliminate this variable is to make each test rather long so as to use a great number of rods and thus cause the rod differences to average out.

The factors involved in welding cost are principally (1) pounds of weld metal deposited per hour, (2) pounds of weld metal deposited per kilowatt hour of power consumed by the welding set and (3) pounds of weld metal deposited per pound of electrode purchased. To determine these factors only as they are affected by the welding generator all weights and times must be accurate, and all times should include only that time current actually flows. Including idle time and cleaning time involves the operator and electrode and not the generator.

The following table gives the results of four comparative tests between pairs of generators. These tests were all multiple pass butt welds between thick steel plates and all with the current adjusted to give the best weld quality. Physical tests of the weld metal deposited have not yet been made. Each test included the deposition of $3^1/_2$ to 4 pounds of metal, and involved the use of 20 to 50 weld rods. The time was automatically recorded by relay operated electric clocks. The deposit efficiency was figured as the ratio of the increase in weight of the plates being welded to the weight of rod melted which did not include the weight of the stubs. This, of course, is a higher figure than the actual pounds of weld metal deposited per pound of electrode purchased, but is the portion of this factor in which generator characteristics are involved.

The arc voltage and current were recorded by recording meters and the value tabulated is the effective average throughout the test. The input and output of the welding set were taken on recording wattmeters and are totalized for each test.

The results shown in the table indicate that the generator giving more constant current does give from 5 to 12 per cent more metal per kw. hr. of generator output, and also raises the deposit efficiency of the electrode, and the pounds deposited per hour.

The results as indicated by the amount of deposit per kw. hr. input to the motor of the welding set show that

Type of Electrode	Welding Set	Excellence Factors A	B	C	Amps.	Volts	Pounds of Weld Metal Deposited Per Hour	Per Ampere Hour	Per Kwh. Generator Output	Per Kwh. Motor Input	Deposit Efficiency
No. 1 Heavy Flux Coated 1/4 In.	1	129	100	129	306	28.3	5.8	0.0190	0.673	0.361	63
	2	131	325	425	296	29.7	5.71	0.0193	0.646	0.354	59.9
No. 2 Heavy Flux Coated 1/4 In.	1	139	100	139	282	34	6.83	0.0242	0.710	0.412	64.3
	2	142	325	461	271	35.0	6.45	0.0242	0.681	0.404	63.0
No. 1 Bare 5/16 In.	3	150	190	285	196	15.5	3.68	0.0187	1.235	0.441	94.0
	4	125	345	431	194	16.5	3.51	0.0181	1.104	0.484	89.0
No. 2 Bare 5/16 In.	3	155	190	295	204	13.8	3.12	0.0153	1.108	0.372	92.0
	4	121	345	418	198	14.7	2.95	0.0149	1.018	0.425	89.5

with sets 1 and 2 which had the same electrical efficiency the improved generator saved power but with sets 3 and 4 the greater electrical efficiency of set 4 over balanced its generator's inferiority and gave the least power cost.

The other factors involved in welding costs such as labor and power costs when not actually welding, factory overhead, scrap, electrode stubs, etc., must also be considered before the actual cost of welding can be figured.

The test has therefore shown that improvements in generator characteristics to obtain more constant current will give faster and better welding both because it improves the metal transfer in the arc and also because it makes it easier for the operator to start and maintain the arc.

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WELDING SOCIETY ACTIVITIES AND RELATED EVENTS

News Items

It is proposed that the WELDING JOURNAL inaugurate a news item column in which there will be included news items relating to important applications of welding.

Important constructional applications such as buildings, bridges, large tanks, pipe lines and welded ships and barges will be included in this section. Novel production applications and items of a similar nature are desired.

It is respectfully requested that all members of the Society who have knowledge of such welding applications refer them to the editor as promptly as possible in order that they may be included in the current issue of the JOURNAL.

JUNIOR ENGINEER

Applications for the position of junior engineer must be on file with the office of the U. S. Civil Service Commission, Washington, D. C., not later than September 16, 1935.

Optional subjects are: aeronautical, agricultural, ceramics, chemical, civil, electrical, mechanical, mining, petroleum and structural steel and concrete.

The entrance salary is $2000 a year, less a deduction of $3\frac{1}{2}$ per cent toward a retirement annuity.

Applicants must have been graduated with a bachelor's degree in engineering from a college or university of recognized standing upon the completion of a full four-year course.

Full information may be obtained from the Secretary of the United States Civil Service Board of Examiners at the post office or customhouse in any city which has a post office of the first or the second class, or from the United States Civil Service Commission, Washington, D. C.

24th Annual Safety Congress and Exposition

The National Safety Council, Inc., will hold its 24th Annual Safety Congress and Exposition in Louisville, Ky., October 14–18, 1935.

Thirteenth Annual Convention of the American Institute of Steel Construction, Inc.

Members of the AMERICAN WELDING SOCIETY are cordially invited by the Officers and Directors of the American Institute of Steel Construction, Inc., 200 Madison Avenue, New York, to attend the Thirteenth Annual Convention of the Institute to be held October 16, 17 and 18, 1935, at the Greenbrier Hotel, White Sulphur Springs, West Virginia.

Special Advanced Welding Course Offered in Cleveland

(*From a News Release*)

Beginning August 26th, a special five-day course in welding engineering is being offered in Cleveland by the John Huntington Polytechnic Institute in cooperation with The Lincoln Electric Company. The course, being repeated at this time due to increased activity in the welding industry and in answer to a demand for an intensive advanced welding training course, will be conducted once each month, except during November, through May 1936. Engineers, welding supervisors and foremen will have an opportunity to engage in intensive study of both the practical and theoretical sides of arc welding. In view of the great interest in past sessions of this course, a full enrollment is anticipated for each of the weekly periods.

The course will consist of day and evening sessions. Day sessions will be held between 10:30 A.M. and 4:30 P.M. at the plant of The Lincoln Electric Company, Cleveland, Ohio, which has offered the facilities of its welding school under the direction of A. F. Davis, Vice-President. Evening sessions at the John Huntington Polytechnic Institute between 7:30 and 9:30 will be devoted to lectures and discussions.

The purpose of the course is to study the arc welding process and its applications to design and fabricating problems. The process will be considered from the arc to the finished product. The following subjects will be covered: value and use of the electric arc; calculation and distribution of stresses in welded joints; study of polarized light and rubber weld models; penetration; designing for arc welding; estimating welding costs; and organizing the welding department.

Important Notice

Immediately upon arrival, Members and guests are requested to register in order to obtain Technical Session papers and A. W. S. Convention badge admitting you to Exposition.

All Technical Sessions and Committee Meetings will be held at the Palmer House, starting promptly as scheduled.

No stenotype reporter. Members of the Society desiring to discuss papers are urgently requested to prepare discussion in writing in advance of the meeting and to send copies to headquarters as those preparing written discussion will be given preference at the sessions. Members and guests giving extemporaneous discussion at meetings should forward a written transcript of discussion as soon as possible after the meeting.

Registration

will be provided *throughout* the *week*, commencing *Monday*, *September* 30th at

Palmer House— 9:30 A.M. to 5:00 P.M.
Amphitheatre (both entrances)—12:00 noon to 5:30 P.M.
6:30 P.M. to 10:00 P.M.

PROGRAM

15th FALL MEETING AMERICAN WELDING SOCIETY SEPTEMBER 30-OCTOBER 4 1935

MONDAY, SEPTEMBER 30TH

Afternoon

OPENING SESSION

1:45 P.M. Introduction of President of American Welding Society by D. C. Wright, Chairman, Chicago Section.

Welcome address by local Official.

Announcement 1936 Nominating Committee—J. J. Crowe, President.

Presentation of Samuel Wylie Miller Memorial Medal—F. T. Llewellyn, Chairman, Board of Trustees.

Monday Afternoon (Continued)

TECHNICAL SESSION

2:30 P.M. Presiding Officer—J. J. Crowe, President.

"Bridge Welding—A Review of the Literature," by F. H. Frankland, Vice-Chairman, Committee to Study Welding of Highway and Railroad Bridges.

"Nitrogen in Metallic Arc Weld Metal," by Dr. J. W. Miller, Reid Avery Co.

Evening

6:30 P.M. Dinner Meeting, Board of Directors, Palmer House.

TUESDAY, OCTOBER 1ST

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—H. T. Heald, Dean of Engineering, Armour Institute of Technology.

FUNDAMENTAL RESEARCH IN WELDING

"Spot Welding Problems," by J. H. Zimmerman, Massachusetts Institute of Technology.

"Bend Testing of Welds—A Summary," by M. F. Sayre, Union College.

"Advantages of Welding in Continuous Structures," by Inge Lyse, Fritz Engineering Laboratory, Lehigh University.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—C. A. Adams, Director, American Bureau of Welding.

FUNDAMENTAL RESEARCH IN WELDING

"Arc Welding with Pure Iron," by Gilbert E. Doan, Lehigh University.

"Investigations of Residual Stresses," by R. E. Jamieson, McGill University.

"Tests to Determine the Feasibility of Welding the Steel Frames of Buildings for Complete Continuity," by W. M. Wilson, University of Illinois.

"Creep Tests of Welds," by N. F. Ward, University of California.

Evening

7:30 P.M. Palmer House. Conference and Meeting of Fundamental Research Committee, American Bureau of Welding—H. M. Hobart, Chairman, presiding.

This conference is scheduled for the assistance of university research workers in the fundamentals of welding.

WEDNESDAY, OCTOBER 2ND

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—D. C. Wright, Chairman, Chicago Section.

"Fabricated Composite Dies," by K. Janiszewski, President, Superior Steel Products Company.

"Welding All-Metal Radio Tubes," by M. L. Eckman, Thomson-Gibb Electric Welding Co.

"A New General-Purpose Meter for Resistance Welding," by C. Stansbury, Cutler-Hammer, Inc.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—G. T. Horton, President, Chicago Bridge & Iron Works.

SYMPOSIUM ON METHODS OF MINIMIZING DISTORTION

1. Pressure Vessels
   J. T. Phillips, Foster Wheeler Company.
2. Repair Welding
   Geo. Hettrick, President, Anchor Welding Service Inc.
3. Light Gage Steel
   J. H. Blaha, General Household Utilities Company.

"Machine Torch Cutting and Fabrication of Tool Equipment," by P. H. Danly, Danly Machine Specialties Company.

Evening

MILWAUKEE NIGHT

10:00 P.M. "Stag Affair"—Entertainment, Sandwiches and Beer—$1.00 per person.

Dining Room, No. 14, Palmer House.

THURSDAY, OCTOBER 3RD

Morning

TECHNICAL SESSION

9:45 A.M. Presiding Officer—Dr. W. M. Mitchell, Illinois Steel Co.

SYMPOSIUM ON LOW ALLOY STEELS FOR WELDING PURPOSES

"The Development and Use of Low Alloy High Tensile Steels in Welded Construction," by A. E. Gibson, The Wellman Engineering Company.

"Welding of Alloy Steels"—
H. L. Miller, Republic Steel Company.
J. C. Holmberg, Struthers-Wells-Titusville Corp.
E. C. Chapman, Hedges-Walsh-Weidner Co.

Afternoon

TECHNICAL SESSION

2:00 P.M. Presiding Officer—E. Vom Steeg, Chairman, Meeting & Papers Committee.

"Welding of Alloy Steels," by J. C. Hodge, Babcock & Wilcox Company.

"Effect of Generator Characteristics on the Weld," by J. H. Blankenbuehler, Westinghouse Electric & Mfg. Co.

"Electrical Characteristics of the Welding Arc," by S. C. Osborne, Wilson Welder & Metals Co. Inc.

"Resistance Welding of Copper Alloys," by I. T. Hook, American Brass Co.

Evening

7:00 P.M. Dinner Dance with entertainment. Red Lacquer Room, Palmer House. Tickets $4.00 per person.

FRIDAY, OCTOBER 4TH

Morning and Afternoon

INSPECTION TRIPS

Unusual arrangements have been made by the Chicago Section to provide first-hand demonstrations to executives of the metal working industry of the varied applications of welding and its general acceptance as a production tool.

The entire day will be given over to these inspection trips. Two routes of inspection will be provided covering various plants in the south and southwestern parts of the city. Individuals registering will be provided optional choice of either route. It is expected that provision will be made for luncheon. The following plants will be visited.

International Harvester Co. (Tractor Works)
Lasker Boiler & Engineering Corp.
John Mohr & Sons
Illinois Steel Co. (South Works)
Clearing Machine Company

It is expected that officials of each company will welcome the Groups.

WELDING EXPOSITION

New International Amphitheatre, Chicago, Ill.

Exposition OPENS at NOON, Monday, Sept. 30th.

Throughout week Exposition will be open every day from Noon to 10:00 P.M. except Thursday when it closes at 6:00 P.M.

LADIES ENTERTAINMENT

Programs and information available at Registration Headquarters.

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